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Breathing Life into the Wooden Model:

A Participant Observation Study of Technical Change

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Declaration

The work described in this thesis is the authors own, except where otherwise indicated, and has not been submitted in whole or in part for another degree at this or any other university.

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Abstract

This thesis reports the results of fifteen months of participant observation study of a major technological research and development project. The project, in the area of advanced factory automation, was part of the British government's Alvey Programme.

The findings bear upon two main bodies of theorectical literature. The first is Marxist literature on technology, the state and the labour process. Participant observation study of this project reveals technological change to be a much more chaotic process than this literature assumes. The process, for example, is not guided by clear capitalist interests. The other body of literature is the 'actor-network' approach of Callon, Latour and Law. In common with them, it is found that technological change is not merely a technical process - it is 'heterogeneous engineering' of both 'technical' and the 'social' simultaneously. However, the actor network theorists overstate the possibilities for this 'heterogeneous engineering'. It is neither as thoroughgoing or as successful as these writers might be read as asserting.

A further conclusion is that the significance of gender for participant observation studies of science and technology has been underestimated. In particular, the gender of the researcher appears to have an important bearing on the research process.

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Preface

This thesis reports the results of fifteen months of participant observation study of a major technological research and development project. The project, in the area of advanced factory automation, was part of the British government's Alvey Programme. This preface provides the reader with a map of the thesis.

Chapter one describes the theoretical background to the thesis. Two main bodies of theory are looked at; Marxist literature and the 'actor-network' approach. In chapter two, I review the UK Alvey Programme. This was a state programme set up to support the development of advanced Information Technology in universities and industry. I look at the organization of the Programme, the particular technologies being supported and one particular method of funding collaborative developments in these areas, the large scale demonstrator projects, one of which is the subject of this thesis. This particular demonstrator project was called the Manufacture from Design project. Chapter three describes the factory of the future and the role of the Manufacture from Design project in this vision.

It is in chapter four that I begin to detail my participant observation study of the Manufacture from Design project. In this chapter I describe how the project was put together, the different collaborators involved and the important characters who appear throughout the study. The social process of technological change begins to be revealed.

In chapter five I look at the technical resources selected for the project. I show that for the participants, the choice of these hardware and software tools could not be separated from a range of social concerns. We see that the participants are engaging in 'heterogeneous engineering' - mixing the 'technical' with the 'social'.

During my participant observation study I was based at the Department of Artificial Intelligence at Cally University. In chapter six we see that within the Cally team, there were competing definitions of what they themselves should be doing on the Manufacture from Design project. We see that different members of the team had different approaches as to how 'technically' revolutionary their work should attempt to be. Although some members of the team considered a technically 'conservative' approach was chosen, the Cally project manager envisaged quite 'radical' changes would be needed in the social world for the Cally system to 'work'.

These projected changes are described in chapter seven. In chapter seven we also see that the industrial collaborators held a different opinion of how the Manufacture from Design project could be useful, which was based on their view that the existing social world was not as malleable as Cally portrayed it. With these different approaches to the 'technical' and the 'social' we see the Cally team involved in a process of 'heterogeneous engineering' to try and bring the industrialists around to their way of thinking.

Central to the rhetoric surrounding the establishment of the Alvey programme was the area of Man-Machine Interface. In chapter eight, I trace what happened as attempts were made to translate this rhetoric into the reality of the Manufacture from

Design project.

Chapter nine concludes the presentation of the material collected in this participant observation study. Obviously, it was important for those involved in the Manufacture from Design project that it be a successful project. But what 'success' meant differed radically from group to group and context to context. In this chapter, I review some of these different meanings of success, and how the participants sought to achieve it.

This thesis began by reviewing some important theoretical approaches which have attempted to explain technological change. In the final chapter of the thesis, chapter ten, I draw together the empirical material of my case-study in order to see how these approaches bear up in the light of such a study. Finally, I consider the implications of gender for a participant observation study of science and technology.

Chapter One

Theory and Methodology

When the British Government announced in 1983 that it was about to fund one of the largest programmes ever in the area of advanced information technology - the Alvey programme - it seemed appropriate to consider the role of the state in technological change. The way I thought that issue should be looked at reflected my background in sociology up to that point. Fresh from a degree that included courses on Marxist theory and its relevance to the 1980s, a class in contemporary social theory that included the likes of Althusser, and an undergraduate project that looked at the efforts of one multi-national electronics company to weather the storm of economic crisis in the 1970s through rationalization and investment in new technology, it made sense to think of technology as *shaped* by a broad social milieu and especially a capitalist one.

But shaped how? In my new postgraduate environment of social studies of science where the concern is with the production of technical and scientific knowledge it was appropriate to ask: how does the state make itself felt at the level of technical practice, to influence and shape technology to suit its goals? Existing theories, mostly Marxist, offered little on this, concentrating on the role of technology in the restructuring of capital and neglecting to look at the role of the state in the *process* of technological development. Typically, Marxist theorists have been concerned with understanding the form of 'the political', to understand why the state does what it does at particular moments in history. As regards government programmes in the 1980s to fund the research and development of particular technologies we would expect these theorists to ask: why is the state taking this political form? But their approach to the state and technology has been disappointing from the perspective of the sociology of knowledge. For example, Hirsch argues that the state's intervention in science and technology has been made increasingly necessary by the instability of a capitalist mode of production, subject as it is to periodic crises. Individual capitals become 'unable to produce and to realize (from the point of view of production technique) the mass of scientific and technological knowledge necessary to stabilize the system as a whole' (Hirsch, 1978, p.80). And so state organized and financed science and technology become the principal means of counteracting the fall in the rate of profit. Hirsch describes the state as an organizational power which, as capitalism advances, 'not only furnishes the general scientific potential necessary for reproduction (basic research, scientific qualification of labour power), but also finances technological developments in individual industries' (Ibid, p.96). But the shaping of that knowledge as it is practised by a community of scientists or technologists does not feature in this theoretical framework. It is taken for granted that technology embodies the social relations of capitalism.

David Noble, however, is a Marxist who has moved away from the theoretical abstractions which plague much Marxist theory and has argued in concrete detail how the technology of numerically controlled machine tools was shaped, and chosen instead of the equally viable record-play-back method (Noble, 1986b). That choice reflected the social relations within which the technology developed. Numerical control won the day as the best means of automating machine tools not as a result of its inherent superiority but because it removed control of production from the workers and put it in the hands of management. In this way the technology mirrored capital's desire for control over labour.

The implication in Noble's work, however, is that actors are clear about their goals and how to go about satisfying them. According to Noble the technologists view the world as management does and management in turn represents the interests of capital. Technologists are unlikely to design something that will not find favour with the dominant group who can put their technology into practice. They share the same ideology and consider only those solutions which are compatible with the existing distribution of power. A technology will be viable only if it conforms to existing social relations: 'So when an engineer begins to design a top-down technical system, he or she reasonably assumes from the outset that the social power of management will be available to make the system work ... their own interests become indistinguishable from their patrons' (Noble, 1986a, p.24). The dominant groups in the political and commercial arenas *know* what they want and they choose the technology that best reflects their goals and interests. The shared culture of those developing the technology and those requesting its production ensures that both sets of goals can be satisfied by the same artefact. That culture, claims Noble, is the pre-existing and permanently influential one of capital's desire for control.

An influential non-Marxist approach to explaining technical change is put forward by Pinch and Bijker in their Social Construction of Technology programme (SCOT) (Pinch, & Bijker, 1984). Pinch and Bijker have proposed that the 'social construction of technology' can be analyzed in the same relativist manner adopted in the 'Strong Programme' of the sociology of scientific knowledge (Bloor, 1976). Technology, they argue, like science, is underdetermined by the physical world, and needs to be explained by reference to social factors. Success and failure must be analyzed in an impartial and symmetrical manner, without any reference to 'truth': 'The success of an artefact is precisely what needs to be explained. For a sociological theory of technology it should be the explanandum, not the explanans'. (Pinch, et al., 1984, p.406).

Pinch and Bijker seek to explain technological outcomes in the same way that the sociology of scientific knowledge explains the 'closure' of scientific disagreements. Firstly, the technological or scientific issue in question is shown to display 'interpretative flexibility' - for example, that there is more than one way to design an artefact, or that more than one conclusion can be drawn from a particular set of experiments. Such conditions are usually apparent only during scientific controversy or in the early stages of the development of a technology, but are always there in principle. A consensus will usually form around one design or one interpretation. This 'closure' is effected by social mechanisms, not simply compelled by logic, or rationality, or efficiency.

Pinch and Bijker, unlike Noble, do not spell out systematically what these mechanisms might be, nor how they relate to the structure of the wider society. Their approach and Noble's are not wholly inconsistent, however. A more fundamental challenge to any Marxist interpretation, to any attempt to explain technical change in terms of a capitalist structure, comes from the network theorists. Indeed the network theorists also attack the SCOT programme for its treatment of 'the social' as an external influence on the design of a technology and as the mechanism reducing interpretative flexiblility by means of closure. The leading network theorists are the sociologyists John Law (, 1987), Michel Callon (, 1980), and Bruno Latour (, 1987) though there are similarities between their position and that of the historian of technology Thomas Hughes (, 1983). Instead of there being a society which intervenes to choose between competing technologies and select those objects which reflect the goals and interests of that society, the social world and the interests of actors within it are created by technologists and scientists. To have their technology accepted as workable or inevitable technologists must engineer the social, economic and political world as part-and-parcel of their technological enterprise. Indeed, according to the network theorists the conventional dichotomy between 'the technical' and 'the social' must be abandoned (Hughes, 1986). For those who juggle around with and rearrange the social world - the heterogeneous engineers (Law, 1987) - there are no distinctions.. The implication of such a 'seamless web', as Thomas Hughes has described the interweaving of the social, economic and political, is that those categories are quite literally up for grabs. External factors, say the network theorists, do not appear at the proverbial 'end of the day' to shape and determine a technological path: technological choice is neither settled by the immutable laws of capitalism nor by the external factors that belong to the empirical programme of relativism's third stage (Collins, 1981). The time of technological change is when the social, political and economic world is in flux. The task of the scientist or the technologist is to convince and persuade people and objects alike to take part in the construction of incontestable facts and technologies: to build black boxes. The system-builder will create new social groups, translate interests and tranform recalictrant forces and keep them arranged and in place long enough to build and disseminate a technology or scientific fact. The result of such activity is a network of associated elements, which, depending on the skill and cunning of heterogeneous engineers to do what is necessary in the pursuit of their goals, may be strong (resistant to dissociating forces) or weak. The ensemble of such networks constitutes both 'society' and ' technology'.

Like Marxists, the network theorist Michel Callon is interested in the form of the state. But he does not agree that state action has to be analysed in terms of the contradictions of capital, contradictions which arise out of the struggle between the classes that form the basic relation of conflict in capitalist society, capital and labour. According to Callon, both social and technical features were apparent in France in the struggle between Electricité de France, Renault and other government groups about the future of the electric vehicle car. He seeks to treat 'the state' and 'electrons' symmetrically. And when he seeks to understand the state's intervention in technology he sees it as the outcome of various actors such as industrialists, state agencies and scientists who struggle to have their interests met (note, not the two *classes* of capital and labour). The state, claims Callon, does not possess the means of deciding which technology to fund in the face of 'technological pluralism' (Callon, 1980, p.375). What the state does lies at the intersection of all these competing actions. Callon would disagree radically with almost all the concepts in Hirsch's assertion that: 'considerable technological backwardness ... can lead to the state apparatus vigorously promoting technological developments when they are of fundemental importance for the reproduction of total capital.' (Hirsch, 1978, p.96)[1].

Callon is not unique in his disagreement with formulations such as this. Latour would also deny that technology is something to be pulled along the various stages of progressiveness to the point of use by an authoritative state. His work on Pasteur shows how it was the scientist who had to persuade the farmers, hygeneists, vets and even rats, fleas and cattle, to take part in the creation of a reliable vaccine that eventually became indispensable to vets, farmers, cattle and the French state (Latour, 1983).

What the network theorists suggest is that different actors are not *obliged* to share the same goals or interests by virtue of any dominant ideology or needs of capital. That actors come to share the same views on technology, that an artefact may be

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[1] Callon's refusal to privilege the state as the organizer of science and technology has parallels with the Marxist theory I have described. Hirsch also recognises that 'individual monopolies can compel the state to take measures to promote technology which are in their special valorization interest, determined by competition on the world market, but which stand opposed to the reproduction of the particular "national" total capital. State technology policy can therefore not be interpreted as the smooth reaction to the objective requirements of reproduction; it is rather moulded in a particular way by the conflict between the partial interests of monopolies and the general reproduction demands of capital as a whole.' (Hirsch, 1978, p.96) However, unlike Callon, Hirsch *does* privilege the mode of production. Unlike 'networking' this moulding is always rooted in the material conditions of capital. Similiarly, Hirsch does not include scientists and technologists as a group who might find a way of having interests at odds with capital.

accepted as working or its results believed, that the state exists and can act, is the outcome of much persuasion, negotiation and even conniving.

An important tool in that persuasion, according to the network theorists, is the scientific text (Gilbert, 1977; Latour, et al., 1979; Law, & Williams, 1982). The scientist or technologist in their laboratory seeks to turn the graphs and tables - the output of the 'inscription devices' - into scientific papers which will solidify into an indisputable fact the claims made for a scientific process or technological artfact. Citing the work of others in the form of references is a strategy used by scientists to tie the results of their laboratory to established fields of work. The reader will be led down the path to accepting the claims as statements of fact as it becomes more and more difficult to dispute the black boxes which are brought in to lend support to the laboratory results. If Marxists admire, however ambivalently, the power of capital, Latour admires with equal ambivalence the power of the laboratory.

Methodology

My methodology is participant observation. It is an approach favoured by many in the sociology of scientific knowledge and technology (Knorr-Cetina, 1981; Lynch, 1982). But that preference is largely rhetorical; there is actually very little ethnography practiced. And what is done is nearly all on science, not technology.[2] When I began my fieldwork in 1984 I knew of only one other researcher studying technology in this way. Since then the field has grown to include studies by Forsythe (, 1987), Walker (, 1988) but it is still very small.

A standard issue concerning participant observation is the effect of the observer on the social setting: to what extent do the native members behave differently in the presence of the observer and have their way of life affected? Harry Collins (, 1983) has argued that it is inevitable that a situation will be disturbed by an observer who is amongst the native members for a long time but that it is something which should not cause concern. The goal of the enterprise is not an 'objective' account of events: the sociologist is not a detective. What is aimed at, claims Collins, is participant <u>comprehension</u> whereby the sociologist has absorbed the culture to the extent of having

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[2]See the 'Laboratory Studies', theme section in <u>Social Sudies of Science</u>, 12 (4), 1982

learned what could reasonably 'count as an account of action' in that social setting.

How does a researcher observe or comprehend another culture? Some ethnographers in the sociology of scientific knowledge have emphasized the use of video camera and audio machines in an attempt to record the practices and talk which are embedded in scientific work. The claimed necessity for such complete recording is, however, based on an empiricist tendency. It implies that the world of science and technology is 'knowable' (Willis, 1977) and that it presents itself empirically to those observing, as a life-form might to an observing naturalist. At the very least, however, technological work is not restricted to sites where the video and tape-recorder can be present. Many events, perhaps of some importance, in the project I studied took place in locations that I think are definitely off-limits for the video or the tape recorder - most notably, the pub). The video lens and the tape machine are of course also more intrusive in practice than the 'human' observer. Wishing that subjects might relax with me, I relied on my ability to listen, to talk with them, record with my eyes and take notes. Such an approach has stood other ethnographers in good stead - most notably F.W Whyte in his sociological classic Street Corner Society (Whyte, 1955).

Participant observation is a popular method - again, rhetorically at least - with the network theorists who advocate following scientists and technologists around in the course of their work.[3] However, most of those doing ethnographic work are men and I am woman. And so just how important gender would be in an ethnography of science and technology is something worth keeping in mind for this thesis. I will discuss this below in Chapter 10.

Being close to the participants means that we are in a good position to witness the extent to which they engineer the world around them as they try to bring it into line with their own goals, if that is what they do. But, of course, in participant observation the observers are not in a vacuum. Participant observation is a mutual process: so at the same time as I set out to understand them and their actions they were making sense of me. 'There are a couple of people I haven't seen round this table before,' one

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[3]One major ethonography has of course emerged from this group, (Latour, 1979). But that was written before Latour became a network theorist, at least in quite the sense ascribed above, and lacks a real successor.

researcher announced loudly at a staff departmental meeting. I was one of the unknowns. The head of the department explained my presence; I was a sociologist. That registered a few blank faces. (My face was probably fairly blank also. I had only recently finished my degree and so I thought of myself as someone 'with a degree in Sociology', not a sociologist.)

But in spite of my title some within the particular group of researchers I was going to be working with ascribed me the status of project psychologist in spite of my repeated attempts to correct them. There was no distinction as far as they could see. Somehow what I was doing was easier for them to make sense of as psychology. That in itself is interesting for what it says about the accessibility of psychology and sociology outside of the social sciences. I was assumed to be doing a project on different personality-types and how that bore on the success of the project. I was assumed to be interested in finding out what sort of person made a good group leader, what were 'his' attributes and why some people were bound to be leaders. It was amusing to see one of those who cast me as the psychologist turn up in smart suits, shirt and ties and sometimes a regimental type researcher announced loudly at a staff departmental meeting. I was one of the unknowns. The head of the department explained my presence; I was a sociologist. That registered a few blank faces. (My face was probably fairly blank also. I had only recently finished my degree and so I thought of myself as someone 'with a degree in Sociology', not a sociologist.)

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I need not have worried about getting on their nerves with the questions which researchers are expected to ask all the time (Knorr-Cetina, 1981). The project leader told me that he found talking to me useful and my questions a way of helping him to formulate what he wanted to say to collaborators, in papers and at conferences. It was as though I were a sounding-board, an aid in his preparations for accounting for or interpreting his work to others. If I seemed to follow his reasons for doing what they were doing then others should also understand.

The observation was not one way. Another team researcher who I was to meet later viewed me, as he said he did 'everything that exists outside of my head.' Similarly he treated me as though I were an object outside his head to be explored. Just as he would have liked more ways to test his programs, similarly I was something to be poked and prodded with argument and counter-argument. In a display of radical empiricism he asked how I could espouse views on anti-apartheid. I had not been to South Africa, how did I know what went on, how could I offer any views. In what got to be quite heated he 'settled' the debate by consoling me that he was only prodding and made a gesture with his finger at me that was reminiscent of those school physics experiments with billiard balls; a sequence of action and reaction.

Whatever the difficulties of participant observation, its desirability - even necessity - for this study was overwhelming. A group of people with a variety of skills and from different backgrounds had been brought together to develop a new technological system in a project under the government's Alvey programme. This represented a chance to witness in 'real time' the social shaping of the technology and to ask what we mean by the 'social': is it the technologists who shape the technological path, a task which at the same time would involve them in rearranging the social world, setting up new social groups and interests? The rationale of Alvey was to involve the state, industry and academia in the shaping of a technology. Would their goals diverge? Did the state hold general interests of capital which differed from industry? What about the technologists? How did those playing a part in the development of a new technology see their world: was it something to manipulate, that they could engineer and wanted to engineer? Or did the path laid done by the Alvey programme clearly direct technologists in how they should both research and develop the technology of the future?

In other words, when large sums of money are devoted to the research and development of advanced information technology - the so-called 'fifth generation' computer technology - in not just the UK but also the US, the EEC and Japan, we need to know as much as we can about how technology and society interact. We need now, therefore, to look at the Alvey programme and its aims in more detail.

Chapter Two

The Alvey Programme

State intervention in technological change is a growing phenomenon in the twentieth century. Its presence has been most notable in the sponsorship of military technology but it is increasingly apparent in civil fields as well. What is striking about the Fifth Generation programme - the programme to advance the state of computer technology beyond the existing state-of the-art - is that states throughout the world, in the West and Japan, are attempting to encourage and direct the technology on a massive scale, involving national, supra-national and co-operative projects. This intervention does not stop at financial support. As well as targeting specific technological areas it also involves the organization and education of the people taking part. In other words intervention involves a great deal of social engineering, to create the conditions in which the challenges of the Fifth Generation can be met.

The Fifth Generation Project: 'the space shuttle in the world of knowledge'

The Alvey Programme was the UK's strategy for research and development in advanced information technology. But it was not an isolated event: it was a response to the Japanese announcement in 1981 of its Fifth Generation computer technology programme which would, it was claimed, make 'a quantum leap over the technology of the last thirty years' (Feigenbaum, & McCorduck, 1983, p.30).

Research projects in computer science, however, are not normally major news. But Japan's national research and development project was claimed to be different. It *had* hit the headlines, and no hyperbole was too grand to describe it. It was a 'technological coming-out party' that was about to herald the start of the 'second epoch' in computer technology (Business Week, 1981, p.66). In more threatening tones it was described as a 'computer science Pearl Harbor' (Quoted in North-Holland, 1984,. p.80). This new generation of computer technology would, it was claimed, make a break with the past by introducing something 'conceptually and functionally different from the first four generations the world is familiar with' (Feigenbaum, et al., 1983, p.30). In this way the Japanese fifth generation project was ambitious in its aim. One contributor to the British study on how to respond to Japan described the programme as an unprecedented attempt to: 'leapfrog current computer systems by developing machines that process 'knowledge' and support human-oriented interaction through natural language, speech and pictures.' (Computer Architecture Group, 1983).

Up until this point computers were used to process large amounts of numerical data; data-processing or number-crunching. But in the wake of the fifth generation these computers were to be described as 'nothing more than calculating machines' (Business Week, 1981, p.66). Fifth Generation computer technology, however, was the 'space shuttle in the world of knowledge' (ibid.). The ambiguity of the metaphor however, became ambiguous only five years later with the Challenger disaster.

The rest of the world was being asked to take notice. To sit back and do nothing was argued not to be a realistic option. A UK response was therefore necessary, according to the report of the Alvey Committee, to compete internationally and to avoid watching a lucrative market in Information Technology go entirely to Japan and the US To this end industry, academia and government representatives contributed to formulating a strategy for a Fifth Generation technology programme in the UK.

The Fifth Generation Technology

It seemed that in the Fifth Generation project no area of software or hardware had escaped attention in the quest for change: there were to be new languages and new ways of organizing computer hardware. And, theoretically at least, the various aspects of software and hardware were interconnected.

VLSI, Very Large Scale Integration, was central to all the national strategies. The attempt to place something in the region of one million electronic components on a single microchip was a research aim with its path believed to be most assured. Then, some argued, it would be possible to use this power to 'enable' a move to a different design architecture for computers: to move from the current von-Neumann architecture to computers that function in parallel.

But computers are useless without the software to run them. Processing power alone was not the key to fulfilling the hype of 'computers that think' which the Japanese Fifth Generation was hailed as. Indeed Artificial Intelligence (henceforth referred to as 'AI') was central to the Fifth Generation's automation of distinctive 'intelligent' human capabilities such as the ability to make inferences. Most of what we do cannot be processed using conventional data-processing techniques. (The skills and tasks and knowledge that we associate with human beings mean that a human toddler in many respects is more sophisticated than the most powerful supercomputer.) AI is concerned with how human knowledge - and ability to understand language, move objects, and reason - can be represented and manipulated within a computer. When we think, it is claimed by some researchers that we think in parallel. In the Alvey programme, 'Intelligent Knowledge Based Systems' (or IKBS), became a major focus of attention: it was termed 'applied AI' and was claimed by the academics to be 'widely acknowledged to be of crucial importance for the future of Information Technology.' (Sloman, 1983, p.1).

IKBS systems use different languages from the ones with which most of computer science is familiar. And in Japan it was 'the promise of innovations in architectures that has encouraged them to bank on incorporating sophisticated AI functions in the fifth generation machines' (Science, Vol. 220 6 May 1983 p.582). The von Neumann architecture was being claimed to 'impose a view of programming as the creation of a sequence of state changes in a von-Neumann computer.' (Kowalski, et al., 1983, p.2) . It limited advances to be made in programming.[1] Instead parallelism would enable programs to be written in languages that resembled the way we think and therefore process the symbols we associate with knowledge.

For these languages and programs to be more than research

[1]See Eloina Pelaez's Ph.D thesis University of Edinburgh 1988, for a history of software in the 1960s. The separation of software and hardware that she describes is undergoing a further transformation in the 1980s as part of the Fifth generation. 'The programming languages in production today are much the same as they were when high-level languages were first introduced twenty-five years ago. These languages are called "high level", because of their independence from the details of the instruction set of any one particular computer. In fact they are entirely machine-oriented, because they impose a view of programming as the creation of a sequence of state changes in a von-Neumann computer. Today there is increasing doubt as to the future viability of these procedural languages, both because of the 'software crisis' to which their use had led and because the von-Neumann architecture on which they were based is likely to be replaced by new developments in computer hardware.' (Kowalski, 1984, p.2)

results within the AI community and go beyond the walls of the laboratory they would have to be reliable. So besides allowing a computer to function, software was important within Alvey to the marketing of Fifth Generation technology. To market a product it should meet specifications in terms of behaviour, performance and price. So the next crucial technology, software engineering, would focus on the use of methods formally to prove reliability. In theory such methods rely on logical deduction rather than the expensive (and possibly fatal in the case of some programs for military purposes) technique of trial and error.

The technologies of VLSI, IKBS, and software engineering were crucial to the products the Alvey Programme would want to produce. They would be synthesized into what were known as deliverables: concrete products geared towards specific ends with economic significance and in areas that had so far evaded attempts to radically raise productivity: design work, clerical/secretarial work, counselling services, medical diagnosis, assembly work in unpredictable environments (DOI, 1982). This synthesis would be incomplete, however, without one further enabling technology. That technology was known as 'Man-Machine Interface' (or MMI). Broadly speaking MMI is concerned with the interface between a technological system and the user. Its place in the project was seen as essential to the design of user-interfaces and to the evaluation of systems. As far as the Alvey Report was concerned, MMI was crucial to the commercial success of the project in its efforts to make technology usable. Indeed I.B.M.'s policy of applying 'usability plans' to its product development was an important factor in giving MMI a prominent place in the programme: 'We want more easily built and used computing systems, and this implies a better fit between humans and computers.' (Sparck Jones, 1982, p.2) But in the UK, MMI was said to lack good general theories about interface design which had led in turn to 'commercial immaturity.' (Fox, 1983). That situation was due partly to the concentration of MMI work in government and industrial defence laboratories where MMI was tied to specific defence applications. The MMI strategy document seemed to recognize that MMI would not be widely known to all members of the information technology community and so introduced its strategy with the question 'What is MMI?'. However, the generic problems that were said to underly MMI needed to come out of the defence laboratories because they were 'of wider significance and relevant to commercial activities.' (Alvey Directorate, 1984)[2].

Forging a good relationship between the user and their machine was fundamental to Information Technology but nowhere more so, it was said, than in IKBS technology. IKBS was claimed to be an obscure and difficult area and had to be turned into an acceptable one. The commercial orientation would mean new ways of thinking about MMI and especially how it related to IKBS. Together then, MMI, IKBS, VLSI and Software Engineering were selected as the four technologies that would enable the UK to market competitive products. MMI, it was hoped, would help to shape IKBS for the market by taking account of the human user. One way to obtain an understanding of the user was to make provision for the user in collaborative projects. Reliable software and industrial interest in creating relevant products were also reckoned by Alvey to be crucial to successful technology transfer. But, according to the Alvey report, a critical way to 'maximize technology transfer' was in the organization of

[2]There is an interesting contrast here between the US programme for Fifth Generation and the Alvey programme at the level of strategy for MMI. In the US, technology was being geared specifically toward military applications. In the U.K. we see with MMI an attempt to turn military applications into generic problems for commercial purposes (EIU Informatics, 1984).

Alvey projects: bringing academics together with industrial teams on joint projects (DOI, 1982). Indeed this type of collaboration was a key aspect of the social engineering involved in the programme.

Until this point I have been giving a 'top down', account of the Alvey programme - its rationale as a form of state intervention in technology. However, an alternative 'bottom up', Latourian account is possible. Why did there have to be a response to the Japanese initiative? Was it just a response to international competition? A simple phrase like 'international competition' suggests something out there impinging on us: it is no different from a technological determinist position. It does not explain the form of competition: why this technology is being promoted at this time in history and why it should be organized on such a scale. What of the social relations that generate this specific form of state intervention? Is it a 'response' to the struggle between capital and labour manifested in a fall in the rate of profit?

One explanation, given to me by a researcher responsible for assessing the success of the Alvey programme, was that the 'response' (and the form of the state) was in fact the result of one man's negotiations within the corridors of power. It is a Latourian explanation that makes the eventual director of the Alvey programme, Brian Oakley, responsible for magnifying the scale of the Japanese programme and constructing it in such a way as to be perceived as new and threatening by British ministers who would then have to fund a similar UK programme. However, given that many countries besides Britain responded to the fifth generation announcement it seems unlikely that it *had* to be made to appear as a threat. But this did not mean that all countries responded in similar ways. While the Alvey programme emphasized the importance of designing technologies for the commercial market, the US Strategic Computing Plan concentrated on technology geared towards the needs of the military.

So what of the part played by the academics, the AI community, in fostering the interest in AI and its relevance to advanced information technology (indeed how did AI get to be part of the Information Technology programme?). The Alvey money was not a special sum of funding put aside for Fifth Generation technology. One of the workers on my project explained how the Alvey money was made available for fifth generation technology: 'The Alvey pot was a pot made from raiding other pots'. In a little known area like IKBS, the academic community was crucial to the formulation of strategy and they stressed the economic importance of IKBS work: there was claimed to be a need for IKBS if the UK was to stay ahead of the competition in Information Technology. But it was not always like this.

In the 1970s, AI had faced problems of credibility. For example, a 1973 report written for the Science Research Council by James Lighthill was critical of AI (SRC, 1973). Robotics in particular was criticized on the grounds that it was not possible to build a general purpose machine. And in general AI was criticized for not being 'socially relevant'. It created a stir throughout the AI community worldwide and it affected the financing of AI in Britain.

But now AI was being hailed as central to the fifth generation programme. That turnaround was rationalized historically by some who had been critical of AI earlier: time, it was said, had not been right for AI in the 1970s. The situation now was said to be different. There was recognition of a need to expand research, development and training in AI. AI techniques were now central to the achievement of the intelligent knowledge based systems which the industrial and commercial world was said to expect to begin exploiting during the latter years of the 1980s.

But how did time get to be right for AI? Had the AI community changed its emphasis? Certainly it was said to be less 'blue-sky' and to be concentrating on more attainable goals (industrially relevant). And it had also experienced some commercial success with expert systems, which was said to be responsible for interest in IKBS or, applied AI. Again, a Latourian account is possible. Donald Michie, a founding member of the AI community in Britain, responded vigorously to the Lighthill Report. He complained it was unfair and in the late 70s and early 80s he set about the promotion of expert systems. (Expert Systems are based on AI frameworks for representing knowledge. The knowledge is specialized, for example medical knowledge and can be encoded in the form of rules.) Michie's activities appear to be typical of the heterogeneous engineer. In order to get industry interested in expert systems he organized conferences and a summer school and directed research into 'relevant' areas. Besides that he used his column in the magazine Computer Weekly to promote AI as an important subject.[3]

The AI community, however, was somewhat confused by recent interest.[4] On the whole, it did not uphold the view that in formulating strategy long term and fundamental AI issues should be sacrificed at the expense of applied work for commercial payoff: that certainly is my impression based on conversations with workers within AI. My contact with them largely post-dates the establishment of the Alvey Programme, but certainly they did not speak as researchers who had engineered a large scale programme.

Their reception of the programme was indeed ambivalent. For some, their concern was with the commercialization of the programme. Alvey was not welcomed unreservedly: they would,

[3]For a detailed account of the history of AI see (Fleck, 1982). Also under way at Edinburgh University is research into the commercialization of AI.

[4]See the article in Science April,1984 "AI leaves the laboratory".

they feared lose their research interests. In the university which is the focus of this thesis they were now being asked to be aware of their place in the real world where they would have to sell themselves and their results and to tune up on some key areas of industrial relevance: expert systems, learning and vision systems. Alvey was welcomed by this head of department as the 'kiss of life' for AI. But for others there was confusion in the shape of: 'Why do they want us? What is it they think they are going to get?

The issue of explaining the Alvey Programme and how it came into being is not the subject of this thesis, however. It bears upon my research to the extent that the project I studied was part of the Alvey Programme. That programme, it is important to note, was not a clear set of guidelines to be given to the technical practitioners on how to shape Fifth Generation technology in the UK: 'Considerable confusion about concepts and terminology exists, and it is important that this be cleared up as soon as possible' (Bundy, 1983). There was a need, therefore, for some social engineering beginning with the organisation of the AI community. For that confusion was one aspect of what a leading AI worker termed AI's 'methodological malaise'. The symptoms of this 'illness' were:

'(a) differences among referees and critics as to the criteria for judging AI research (b) the fragility of AI programs (c) the difficulty of rebuilding AI programs from published descriptions' (Ibid, p.3). But the malaise was something Bundy felt could be cured if researchers could, 'agree on the nature of AI, on the methodology for pursuing it and on the criteria for assessing it' (Ibid.). A step in that direction was Bundy's catalogue of AI which had been produced to encourage members of the AI community to communicate. That would be achieved by 'announcing the existence of techniques and portable software, and acting as a pointer into the literature[5]. Thus the AI community will have access to a common, extensional definition of the field, which will: provide a common terminology, discourage the reinvention of the wheel, and act as a clearing house for ideas and software'(Ibid.).

Similarily, it was claimed by the the joint Science and Engineering Research Council and Department of Industry's Industrial Awareness group that industrialists were not clear on

[5]This catalogue was first compiled as part of the IKBS Architecture Study, (Bundy, 1983), and was later published seperately as a book, (Bundy, 1986).

what benefits they could get from AI. A major obstacle to getting IKBS taken up by industry was said to be a lack of awareness among industry's decision makers - senior executives - about the benefits of IKBS. A report on IKBS marketing and awareness stated that, 'An IKBS initiative must have the support of a wide subset of UK industry - IT users and potential IT users. A prerequisite commitment from wide sectors of industry is a real understanding of the issues of IKBS and the potential benefits to be accrued from their use. We argue that this understanding is at present deficient. In the absence of a minimum threshold of understanding, any major publicity initiatives are to be unsuccessful by failing to reach and convince industrial sectors responsible for executive decision' (Industrial Group Report, 1983). This process of social engineering it was claimed 'will not be easy or informal. It will require a great deal of thought, organisation and preparation: because IKBS is an obscure, difficult area of which most senior management will know virtually nothing' (Fox, 1983, Vol. 1, p.30). And so the education of executives was considered to be a necessary component of successful technology transfer.

The programme's industrial awareness, marketing and demonstrator group recommended that there be 'real EXEMPLARS of large knowledge based systems' to provide statistics and benchmarks for acceptable IKBS on which executives in industry could base decisions. Awareness programmes were to run alongside the research and development programme. Uncertainty as to the benefits would involve education of industry: educating the technical community about user needs; getting potential user companies and other organisations to educate researchers in universities and industry about their real requirements for IKBS.

The so-called Demonstrator projects would be one such benchmark important in helping to render IKBS available for decision making by senior executives to use and consume information technology. The Demonstrator projects were to be 'prototypes of possible future systems'. The Science and Engineering Research Council and Department of Trade and Industry IKBS Architecture Study made it clear that the 'initiative for Demonstrator Projects..... [setting them up in the real Alvey world].... must come from Industry, rather than Academia.' (Wilks, 1983, p.2). The Demonstrators were not to be stages involved in the production of a very complicated electro-mechanical product, meant that it was taking on board the building of what was known as the 'The Factory of the Future'. In order to provide background to this particular Large Scale Demonstrator project, it is to the factory of the future that I now turn.

Chapter Three

The Factory of the Future

The 'Manufacture-from-Design' project that I studied for fifteen months was one of the Alvey programme's four Large Scale Demonstrator projects. As mentioned in the previous chapter these were large scale projects designed to produce prototype advanced information technology products. The intention was to demonstrate the utility of the products and thereby create 'market pull' for fully commercial products produced by the companies involved in the programme. They were show pieces for IKBS and the other targeted technologies to demonstrate that this technology could be shaped into products worthwhile to industry. A vital element of the demonstrators was their composition: a mix of industrialists and academics with the hope that the former could shape results in the laboratory into commercially valid products. The demonstrators were not complete without a 'user', an industrial collaborator who would intend to use the finished system. That way, it was claimed, the utility of the project could be demonstrated.

My first introduction to the Manufacture from Design project was a description of it in an early issue of Alvey News: '["Manufacture from Design"] is the title of the system proposed by the Factory Automation System Technology division of [British Electronic Businesses] working with the Artificial Intelligence Department of [Cally University]...The system will ultimately allow design concepts to be input at one end and the product which includes maintenance data, to come out at the other. The demonstrator will provide a skeleton system for the whole process, with human intervention being kept to a minimum. The system will do automatically most of the detailed design work, process planning, machining of parts and assembly' (Clarke, 1983).[1]

A Response to Industry's Needs?

The project's goal was claimed to be a response to growing interest and concern about manufacturing industry: ' This ambitious project addresses an area of the highest importance to British manufacturing industry.... the aim is to develop a new

[1]Manufacture from Design is a pseudonym. So too are British Electrical Businesses and Cally University. A complete table of collaborators appears in chapter four.

generation of computer integrated manufacturing. This integrated approach is applied from the design stage through production planning and automated assembly to field maintenance and support. At all these stages IKBS techniques will be used to capture and apply the skills and knowledge of human operators' (, 1984). The way things happened on the factory floor affected productivity and it was that which was said to need changing in an environment of increasing competition: 'Nations that have enjoyed competitive advantages in the past find that the technologies they previously exploited so successfully can no longer give them the margin of profit required to remain competitive. These industrialized nations are re-discovering that they need more advanced manufacturing technologies' (Suh, 1984b).

A 'factory of the future' was fast becoming a familiar rallying cry to manufacturing industry. New journals were claiming to have been 'born in this challenging climate ... hoping to provide the intellectual base that can accelerate the practical implementation of industrial manufacturing technology based on computers and flexible manufacturing technologies' (ibid.). To be competitive, it was claimed, most companies would be forced to adopt new manufacturing technologies. And for the technologists themselves Advanced Manufacturing Technology gave them much to look forward to, 'The thought of the "Factory of the Future" is certainly exciting and enticing to engineers and technologists. It will enable us to put into practice all those wonderful technical accomplishments of the past and which are possible through further research and development' (Suh, 1984a). Conferences on manufacturing were also dedicated to encouraging changes in manufacturing and offered advice on how to build the factory of the future[2].

All these sources claimed that the key to success was to see the whole of the manufacturing process as a totally integrated activity from the arrival of the raw material to the delivery of the finished product. When envisaged this way, manufacturing was not a series of discrete physical operations that went into making a product but a process of information flow, where 'machines and people are told what to do on the basis of creating, sorting, transmitting, analyzing and modifying all the data involved' (Financial Times, March 14, 1983). For such an

[2] For example, a Conference organized by Arthur D. Little Inc., "The Strategic Benefits of Computer Aided Manufacturing" London, March 1983. (1983)

information flow the various aspects of production would have to have access to a common database. That was the so-called essence of Computer Integrated Manufacture: 'an electronic collection of all the relevant information about the design, production and materials of the product - to which all the interested people and machines have immediate access' (ibid.). As information moves between the stages of manufacture - design, planning, machining and assembly - so it moves from computer aided design systems, to numerically controlled machine tools to robots. This requires the instructions to set the appropriate machine tool in motion, then to perform operations like drilling, milling or turning in an appropriate order before moving onto the assembly stage where the various components are put together. All that requires a great deal of management: machines have to be scheduled to receive the material at the planned time. That in turn requires a lot of knowledge about the process as a whole.

In a computer-controlled network AI had a role to play in this management. Activity in industry was said to be at present a piecemeal activity guided and coordinated in an approximate manner by the judgements, experience and interactions of the management and the workforce. But the application of Advanced Manufacturing Technology could be a means of assisting judgements and decision-making by processing information in a predictive way and reducing the dependence on intuition. And 'In the future the use of artificial intelligence, including "expert systems" where human experience and know-how are incorporated within a computational framework can be looked on as an important development of AMT, aimed at improving the exploitation of industrial methods and/or retrieving information' (Heginbotham, 1985)

'Automate, emigrate, or evaporate'

Not only could what the collaborators were attempting to do be presented as part of a recognised problem facing manufacturing industry but also the Manufacture from Design collaborators themselves were not unique in attempting to build a factory of the future. There were others interested in what was being described as 'The race for the automatic factory' (Fortune, 21 February, 1983). In the United States major companies like General Electric, Westinghouse and IBM were all making plans for future factories. For General Electric the move into 'the emerging megamarket of factory automation' seemed inevitable. Employees sported T-shirts that read 'Automate, emigrate, or evaporate,' the slogan used...to jolt customers into modernizing their factories' (Fortune, November 11, 1985). By getting into automated factories General Electric was changing its corporate strategy away from consumer products, nuclear power plants and jet engines. It was aiming to become the biggest supplier of factory automation equipment in the US and Europe. An announcement which the Mayor of Lynn, Massachusetts called the 'greatest thing that ever happened' (Schlefer, 1985, p.24).

A Crisis of Profit?

These participants' views are echoed by those of academic analysts, though these naturally often do not share the Mayor's facile optimism. The economist Raphael Kaplinsky cites the growth in competition, the faltering of global economic expansion and the emergence of depression brought about by the twin problems of conflict between capitals and the conflict between capital and labour as the motivating forces for capital's introduction of more and more highly automated technologies (Kaplinsky, 1984).

The Manufacture from Design project can easily be seen as fitting within this framework of explanation. The collaborators, it could be said, are being swept along, by the tide of economic necessity, to introduce automation technologies in the hope of making sufficient margins of profit to survive an increasingly competitive environment. Kaplinsky has tried to explain the 'progression' of automated technology as separate processes to the eventual 'factory of the future' where the various 'spheres' of production are integrated: under computer control the operations of design, planning, machining and assembly are co-ordinated. This in turn would allow manufacturers to be flexible in production: they can change the batches of a product from large to small by altering the programming instructions. This would mean that machinery would not have to be reconfigured or disbanded everytime a production run changed. It was in the area of small batch production that Computer Integrated Manufacture would, it was claimed, make a big impact. The small batch producers could respond quickly and easily to the market whenever demand for a product changed. Kaplinsky's historical argument interprets the strategies of firms such as General Electric, IBM and Westinghouse as a response to a global economic crisis which has its roots in a post-war economy.

A Crisis of Control?

David Noble has argued that technical change in the workplace is shaped by managements wish to control and deskill labour (Noble, 1986b) . In his view, the drive to the factory of the future is no different: motivated by the desire to control labour, technologists, the military and management proceed to subject more work on the shop floor to the control of management. AI is just a further development in the continuing trend to turn human experience and skills, the 'know-how' of manufacturing into a machine-readable form. Indeed AI makes it possible to wrest control from so-called mental labour: the designers (Cooley, 1981). For David Noble profit is not the motive for the change in technology, but instead it is the continued desire of capital to control and dominate labour which feeds the drive for total automation: 'Propelled anew by intensifying competition and the increasing cost not only of labour but of energy, raw materials, and capital, and driven as before by the interwoven impulses of management, the military, and technical enthusiasts, the rush toward the automatic factory and the queer quest for a perfectly ordered universe continue unabated' (Noble, 1986, p.328).

'Inside tomorrow's factory'

What then were Manufacture from Design's collaborators' plans for a factory of the future? An early description of the Manufacture from Design project put the collaborators goals somewhere in the past instead of the future: the article explained that the drive to tomorrow's technology was an attempt to get back to the days of the 'craftsman' when the knowledge of design and manufacturing were combined in a single person. A history of mechanization, it was claimed, had separated those tasks and created the problems manufacturing was now faced with today. The aim of the project was therefore: 'to re-integrate design and manufacture in the highly automated workshop of the future' (Financial Times, April, 1983).

The project was considered to be challenging and ambitious in its plan to get back to this time but with advanced technology, specifically the techniques of AI. AI may have been thought of by many people as a subject 'for the birds' but the Manufacture from Design project was, according to a BEB spokesman, a collaboration between 'some hard-headed firms' and universities intended to address the 'real' problems of manufacturing industry (ibid.).

The factory of tomorrow, however, was far from being anything like a working ensemble of the sophisticated Fifth Generation software and hardware applied to manufacturing. The Manufacture from Design system began life as something more like a child's toy. A wooden table-top model showed a designer sitting in front of a control terminal issuing commands which automatically translated into instructions for the stages between the arrival of the raw material to its final appearance as a salable product. But this wooden model, which must have looked so out of place on a desk in Britain's largest electronics company, was an ideal, a projection into the future. The collaborators of Manufacture from Design had five years to 'breathe life into this wooden model, and make it the world's first fully integrated factory...under the guidance of a thinking computer' (ibid.). I was going to witness them perform this metamorphosis. But how was it to be accomplished?

Although almost every article about Computer Integrated

Manufacturing, or CIM, was accompanied by a block diagram depicting elements of production connected up to one another by arrows, showing an ideal state of integration, the route to CIM was acknowledged to be uncertain and not without hitches. There seemed less certainty about what that next move would consist of or how far off the factory of the future would be: 'AML+PC=CIM?'[3] asked one article, while another stated 'Tomorrow appears to have run into a little trouble' as customers resisted taking on board the output of robotics manufacturers (Financial Times, September 8, 1983)[4].

As we follow the actors trying to breathe life into the wooden model, will we find what they do determined by something outside of them - an autonomous logic of technology, economic process or the demands of capitalist domination? Or will they be like Latour's system builders, creating technological trajectories, markets and social groups as they go along?

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[3] A Manufacturing Language plus a Personal Computer equals Computer Integrated Manufacturing? (Sharon, 1985).

[4]Equating assembly with robotics exaggerates the extent of their use. For example one article on factory automation is entitled: 'Robots: why tomorrow has been delayed'. (Financial Times, September 8, 1983)

To start with, however, we need to know something more about who the actors were, and what brought them together.

Chapter Four

Building a Project and a Team

The Project Proposal

One of my earliest introductions to this drama and its players came in the shape of several large ring binders: the so-called 'Study Report'. The following is a list of the principal actors who feature in my story.

Dramatis Personæ.

Cally University: (Artificial Intelligence Department)	Peter Crigbank (Chief Investigator)
	Working on designer system. Jim Watson (site manager) Tony Innes (programmer) Craig Ward (programmer) Howard Jacobs (programmer) Mark Robbins (programmer) Helen (1^{st} secretary) Paula (2^{nd} secretary) Professor Smith (head of dept.)
British Electrical Business (BEB): (Industrial Collaborators)	*Managing Manufacture from Design project* Bill Wilkie (1^{st} overall manager) Tracey Hall (software manager) Alan Rogers (systems manager) Phil Mann (Demonstrator Definition Coordinator)
BEB Assemblers: (Division of BEB)	*Assembly:* Nancy Thomas (site manager) David Curtis

BEB Machines: (Division of BEB)	*Factory Control:* Gordon Collins (1st site manager) Reg Scott (2nd site manager)
Reams: (Industrial collaborator)	*End-user of the system: providing factory environment for demonstration of manufacture from design. Also providing knowledge about design of fuel injection pump: the end-user product.* Eric Cater(site manager)
Human and Technology Interface Institute (HATI):	*Concern is with socio-technical systems and the usability of the designer system.* Frank Jackson (lst site manager) Clive Mint (site manager/researcher)
Deen University:	*Working on solid modelling.* Joe Blair (site manager/programmer)
Talcot University:	*Working on process planning.* Sam Parsons (site manager/programmer)

NB: Other collaboratorsinclude: BEB Avionics working on maintenance. And a Government Laboratory responsible for robot calibration. They do not feature in this storysince their influence at this initial stage of the project was minimal.[1]

[1] But for those on the project - and more often management - it must be remembered that there were often uncertainties about *when* a site should be making a contribution. Concerns were something like; when should the maintenance group be contributing? The uncertainty was with whether Alvey would be expecting to see maintenance work tackled as reports were submitted on the progress of individual site work.

The study report was the proposal put to Alvey for acceptance as a large scale demonstrator project and as such it was a compilation of the 'technical' contributions to be made by the, initially, nine collaborators. Each particular expertise would correspond to a different aspect of the manufacturing life-cycle, from design through to machining, assembly and maintenance. The aim was to create a manufacturing system 'where all the stages are almost all automatic' in order to 'allow human intervention to be kept to a minimum' (Study Report).

In pursuit of this goal it was necessary 'to capture the skills and knowledge of the human operatives used in the manual counterpart.' It was current practice, the report claimed, for manufacturing information to be transferred by means of engineering drawings. The human producer and recipient of engineering drawings converted 2-D lines into orders for raw materials, instructions for machine tools to perform operations, and information about how to assemble the component. In other words, more and more information is derived from and added to a drawing. This is possible, the Report suggested, because the various people involved in turning a drawing into a functioning component share a 'large common knowledge base'; everyone in the process shares the language and the ability to understand and interpret the conventions, implied instructions and manufacturing practices.

But that, according to one spokesman for the project, was a process 'fraught with problems.' With so many people involved 'Mismatch between their work results in faults. There is the ever-present possibility of human error. Often design problems remain undetected until the cost of their error is considerable.' The task of the collaborators, then, was to by-pass the engineering drawing by letting a design knowledge base - the designer system - talk directly to the machines which cannot read drawings. To achieve automation it was going to be necessary, the Report claimed, to convert that human knowledge into a form that could be used by an automatic plant. Therefore, it was suggested, since this common knowledge base was set in motion from the moment the designer put pen to paper it was crucial to begin the automation process at that stage. The purpose of the project - to demonstrate that a system could be developed that would 'capture and use such a common knowledge base' - meant that the producer and the recipient of engineering knowledge were not going to be human beings but computer hardware and software. In the Manufacture from Design project, therefore, it would be computer hardware and software which would have to share a common knowledge base. And that was the principle of Computer Integrated Manufacture.

Thought to be important to the project by all the collaborators was the designer system to be developed by the team of AI researchers at Cally university. They were going to be responsible for building the intelligent knowledge base through which it was suggested the other collaborators programs would be required to interact. The knowledge base would essentially have to represent the knowledge of mechanical engineering designers in a way that would make this possible. Deen University were to work with Cally on geometric modelling of the design of a component. Talcot University were to write the process planning program which worked out what machine tool operations were needed and in what sequence to machine the component described in the design. Talcot's program would need access to the information about the shape of a component provided by the geometric modeller developed by Deen. After the machining operations have been planned, this information is used with the machining knowledge provided by another BEB company, BEB Machining to drive the machine tools. BEB Assemblers were responsible for the assembly of the parts by their Bluebottle robot. Parts in turn may have to be conveyed between machines; in this case Automated Guided Vehicles (AGV's) were to do the transporting.

In order to make the project 'realistic' it included the user group, Reams, a large producer of fuel pumps. Reams would contribute their design expertise in building fuel pumps to build the knowledge base for a fuel injection pump composed of over 200 parts. How these parts were designed and went together to pump fuel at a certain pressure was the task of the designer system. The pump, which was believed to have a great deal of market potential, was to provide the data for the knowledge base.

These contributions were intended to break down the barriers to integrated automation by creating, at the design stage, the instructions necessary to set in motion the operations of planning, machining and assembly. In the Study Report these various contributions culminated in cartoon-like block diagrams: a possible factory layout of the future and the flow of knowledge that was necessary to achieve that.

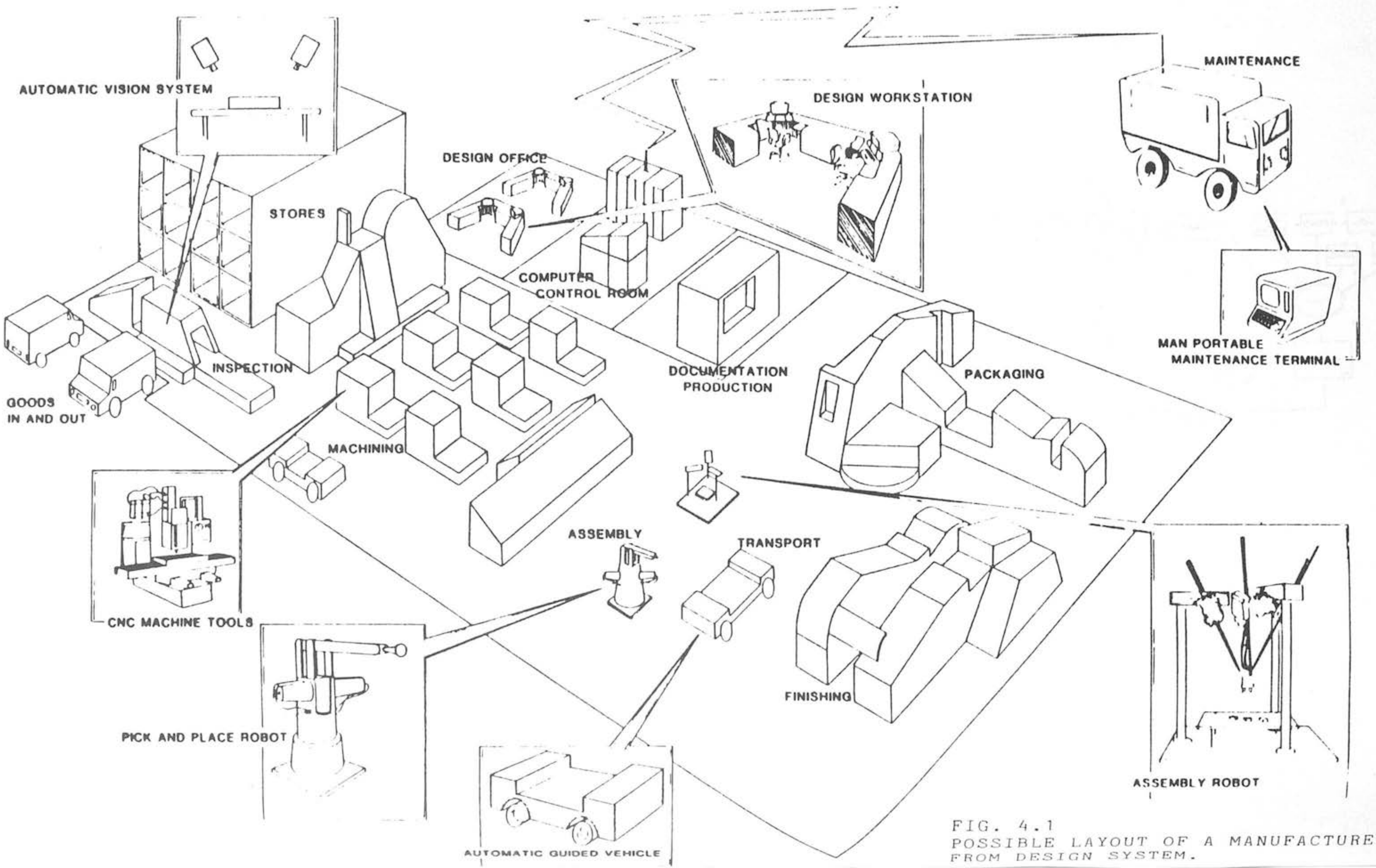

FIG. 4.1
POSSIBLE LAYOUT OF A MANUFACTURE FROM DESIGN SYSTEM.

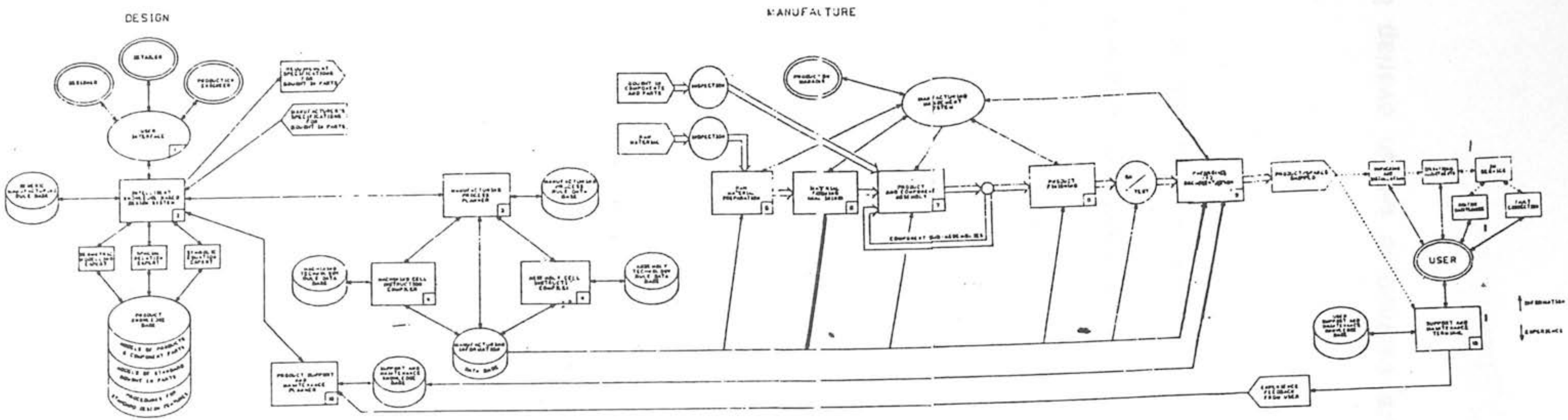

FIG. 4.2
BLOCK DIAGRAM OF POSSIBLE
MANUFACTURE TO DESIGN SYSTEM.

A lot of the Study Report made no sense whatsoever to me. It was really only the introduction and the conclusions I could follow. They seemed to justify the existence of the project in language and with reasons with which I was familiar: the dictates of international competition and a response to the calls made by British manufacturing industry to do something about inflexibility in manufacturing - especially in the areas of small-batch manufacturing and mechanical engineering. The emphasis was on 'products of relevance to British industry'.

Competition would get steadily fiercer and the UK market would remain stagnant, the Study Report claimed: 'Manufacturing industry is not in a good position to meet this challenge, not just because our productivity lags behind that of our major competitors, but more importantly because the UK is suffering from a critical shortage of production and manufacturing engineers and designers ... It is essential to make use of new technology in our traditional business areas to improve our competitiveness.'

At this stage there seemed to be an overlap between the project and the outside world with which I could make some connection. The project was claimed to be a response to this problem. Somehow the bits and pieces described in the middle of the Study Report would have to go together to solve the problem.

But was the Manufacture from Design project a straightforward *technical* answer to the problems of manufacturing? Manufacture from Design had a history, a background, which suggests that the formation of the Study Report and the relationships which were said to exist between the various aspects of manufacturing were much more complex than that.

From little to large: the antecedents to 'Manufacture from Design'

1: Putting the cart before the horse: The Relationship between Design and Assembly.

The Manufacture from Design project had a precursor in the shape of a project entitled Design and Make. That project, I was told, had been hatched from an association between Cally's chief investigator Peter Crigbank and staff from BEB Assemblers who met on the Robot Working Party funded by the Science and Engineering Research Council. BEB and Cally had initially been interested in the robot language Rapt developed at Cally as a way of representing the information necessary to drive the BEB force-sensing robot. The Rapt language was a high-level AI language for robots. Rapt described the way objects went together to complete an assembly operation in terms of their spatial relationships: 'In RAPT we need to describe assemblies of complex bodies and the actions required to bring them together. A situation is a state of bodies composing the robot's world, which state the programmer has chosen to describe, usually by specifying spatial relationships between features of some of the bodies. ... Bodies are described in terms of their features which are plane faces, and cylindrical shafts and holes.'

FIG.4.3
RAPT CODE AND BODIES BEING
RELATED

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MINROB = SUBASS/AGENT,PERM;
AGAINST/HTOP1 OF SLIDE1,RLTOP1;
AGAINST/HFRO1 OF SLIDE1,RLFR01;
REMARK. These two statements specify that the square rail
        fits the square hole in the SLIDE1;
FITS/RGPEG1,SHOLE1;
FITS/RGPEG2,SHOLE2;
REMARK  These last two statements determine that the
        right gripper is only able to move vertically with
        respect to the slide;
FITS/RGPEG3,LGHOLE1;
FITS/RGPEG4,LGHOLE2;
REMARK  So the left gripper can only move horizontally
        with respect to the right gripper;
TIED/RIGHTG1,LEFTG1;
REMARK  The left and right gripper are initially tied;
TERSUB
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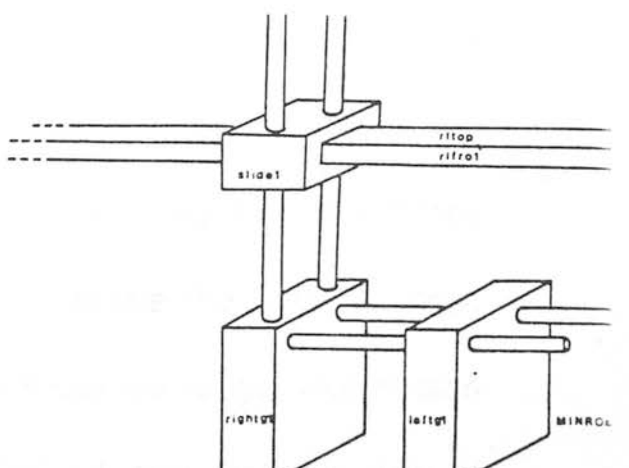


Fig.4 MINROB: The (hypothetical) robot used i example.

Cally and BEB, however, stopped talking about robot languages per se and started talking about design, said Cally's chief investigator Peter Crigbank. An application was needed for RAPT and so RAPT became a way of talking about the design process.

The search for that application led to the Design and Make project proposal. Design and Make proposed a different way of considering the relationship between design and assembly (and to a limited extent machining). And that, Crigbank suggested, 'partly arose from my observation, that others had made, of course, that how you tell robots what to do is tied up with what they think they are doing which means knowing what they are assembling or what they are working on. Therefore it's useful if they have access to design information. Most people who considered the relationship between design and assembly had put the horse before the cart. I, however, put the cart before the horse. When the horse is in front most people would say we've got this design information, we will use it to drive robots: I said that this way of talking about the way things go together, how parts are related to one another captures a lot about design ... spatial relationships which is actually a good way of talking about design.' No longer confined to just robots, the RAPT language was put forward as a way of dealing with the integration of design and assembly.

To prove the feasibility of this relationship the Design and Make project was to involve only a few collaborators (principally Cally and BEB), concentrating on the design and assembly of a robot gripper for a period of 3 years. However, the Design and Make project had failed to convince the Science and Engineering Research Council that there was a place for it within any of its existing categories: each department saw Design and Make as the business of another with the result that Design and Make ended up 'falling between two stools', as it was historically referred to within the project. However, not long after Design and Make's failure an opportunity came along for it to get funded as something else. That was Manufacture from Design. Manufacute from Design, I was told, had grown out of Design and Make. But in what way?

2: A shower of gold and a big bucket to catch it.

'When Alvey came along', as Crigbank put it, it represented a 'shower of gold' to the failed Design and Make project. However, according to one of Design and Make's original founder's, David Curtis from BEB Assemblers (research), there was no Computer Integrated Manufacturing slot within the Alvey programme into which the Design and Make proposal could fit. Not wishing to see it again fall in between two stools (i.e. not wishing to see it suffer the same fate as it had done previously) there had to be a way of getting the project accepted. Large Scale Demonstrator money was seen to be a way to get funding. There was never any doubt about what should be a demonstrator project, according to Crigbank: 'The AI department at Cally had not discussed several possibilities for a demonstrator project - it was Design and Make from the beginning.' According to Crigbank, 'Alvey had postulated the existence of Large Scale Demonstrators and we wanted our paws on some of that money.' To that end Design and Make became Manufacture from Design.

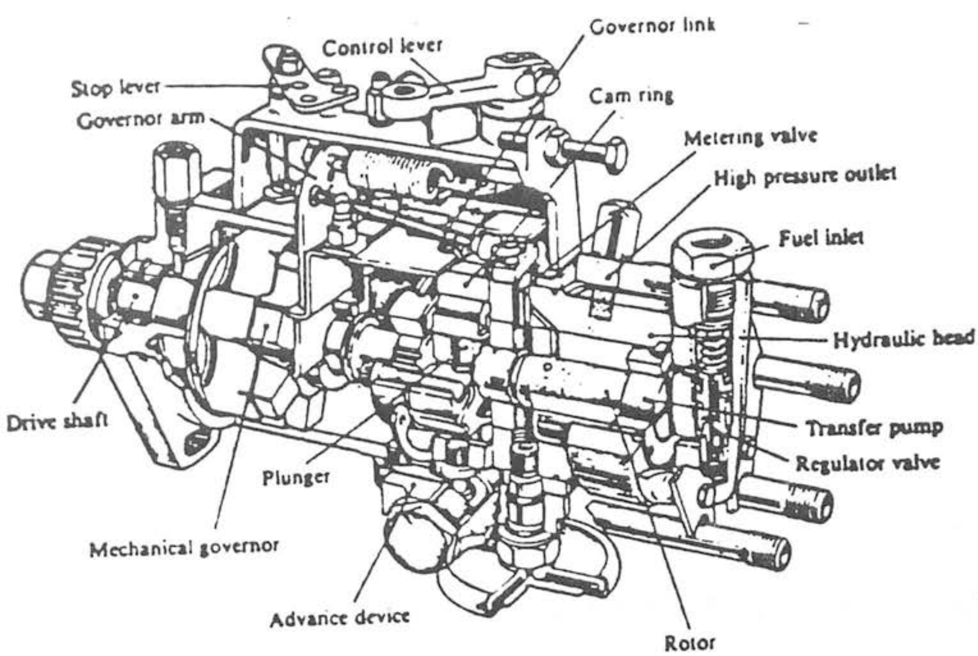
BEB and Cally set about changing Design and Make's spots in order to get the money. As Crigbank put it, 'Alvey was a shower of gold and we needed a big bucket to catch it.' An important step was to change the name from the homely, 'Design and Make' to

'Manufacture from Design' because as Crigbank put it: 'manufacture sounded much more commercial.' The change of name was much lamented by Crigbank. A big bucket needed to be constructed: 'because we wanted to paint a canvas of a Large Scale Demonstrator for Alvey and we wanted more money.' The project, Crigbank told me, was dealing with the problems of British manufacturing and competition, 'because we wanted the money.' A bigger bucket was an increase in the number of collaborators from Design and Make's two, to the nine of Manufacture from Design's project proposal: 'There was more money so therefore it had to be larger scale. If there is more money and you can't spend it all on computers you are going to have to involve more people. We couldn't spend it on trips to the Bahamas. That was enough money to do the technical work. I'm not a frenetic empire builder: that was enough to get on with it.'

A mixture of considerations seem to have been involved in the selection of collaborators. For example, although Cally wanted the modelling skills of Deen, they also wanted to work with another university, believing that way they would have more in common, and get along better than if they got the modeller and modeller skills from a commercial firm. (However what it meant to get on with is not always explicit. BEB choose Reams on the grounds that they were likely to get on well with them as a user group: there could be few fights over exploitation.)

And involving a user company meant a different product to be made. Indeed it was a product for which Reams had high hopes of commercial success. A robot gripper is not uncomplicated in its composition but it is a lot less daunting than a fuel injection pump whose 200 parts must synchronise to pump fuel at the right pressure at the right time.

FIG. 4.4
FUEL PUMP.



That a place was established for Manufacture from Design within the Alvey programme was most likely helped along by the role of BEB personnel within the Alvey programme. As Crigbank put it: 'Corporations are not monoliths, indeed some would say that BEB was Alvey. After all BEB had a lot of involvement in the programme.' That an ex-BEB worker was in control of the Large Scale Demonstrator projects may have helped to secure Manufacture from Design's place in the programme. This was a point noted by Crigbank at a meeting to choose whether Manufacture from Design or another similar project should receive the Demonstrator funds. The Manufacture from Design collaborators were apparently in competition with another consortium who were also tackling integrated manufacture. Crigbank remarked on the difficult task faced by the BEB employee in control of the Large Scale Demonstrator funds. A meeting was held to choose which of the two consortiums were to get the funding for a Large Scale Demonstrator project. Crigbank looked back on the episode and recalled with a laugh, 'To give Lawrence his due he did try his best to be impartial!'[2] The

[2]The role of BEB within the programme raises some important questions about the relationship between big business and the state. It was afterall a frequent complaint of the programme by small businesses that the big electronics companies were dominating Alvey funding and held a disproportionate share of the projects. By June

process planning collaborator that Cally had wanted was forfeited for a BEB choice, Talcot university. It was, said Peter, just one of those things. BEB Machines were going to be working closely with the process planning collaborators. They were friends, 'we decided to work together over a drink one night', a member of the BEB Machines team told a gathering of collaborators.

However, the Manufacture from Design's project was not a complete moulding of the Alvey programme's Demonstrator funds. In one important respect the original Manufacture from Design's project proposal was not quite a big enough bucket to appear 'complete' to the policy planners. One technical factor was missing from the scenario: Man Machine Interface, MMI. Without this contribution the Study Report was deemed to be incomplete since MMI was being hailed as crucial to the success of the programme, specifically its commercial success. A technology which could be *used* by real designers was a technology which would sell. And so with the Manufacture from Design's inclusion

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1987 BEB held the most number of projects, 51 out of a total of 197 projects in a programme involving 115 firms. Although not chronological with this case-study it is a statistic that throws some light on what is meant by a *national* programme.

of the team of MMI specialists, from the Human and Technology Interaction centre, HATI, the proposal was nearly complete. However, one final crucial piece of heterogeneous activity remained in order to secure the project. That was to convince Alvey that the technologies in the proposal together constituted a Large Scale Demonstrator project and not Enabling Technology.

Knowledge Creation or Knowledge Application?

The central issue was to define the status of the project. Was it to be the creation of new knowledge, or the application of existing knowledge? Where was the project to be located on the continuum from 'science' to 'technology', from 'fundamental research' to 'development of a product?'

It may sound strange that this was an issue at all, that it was not self-evident. But, as studies of the relationship between science and technology have shown there is no clear-cut cognitive difference between these apparently quite distinct activities. Rather, the boundary between them is a constructed one (see Barnes & Edge, 1982, Part Three).

Which side of the boundary to place Manufacture from

Design on was an important issue for several reasons. BEB had commercial interests in shaping the Manufacture from Design project into a Large Scale Demonstrator project and not into enabling technology. An important feature of the Large Scale Demonstrators from the point of view of the Alvey programme was that they should encourage technology transfer by bringing academics and industrial teams together on joint projects. And in terms of the programme as a whole it was intended that the demonstrator projects should provide the 'technological hooks' on which to hang the more research-based enabling technologies areas: IKBS, MMI, VLSI and Software Engineering. In this way it was intended that the demonstrator projects provide direction to enabling technology. To do this it was intended that they have a more assured research path in order to act as a 'pull' on the enabling technologies. The demonstrators then were not being seen by the policy planners in terms of the traditional hierarchical model which treats technology as applied science or the linear model of the development of a product as the application or extension of fundamental research. Rather the more assured paths of the demonstrator projects were to feedback into the cognitive resources for the enabling technology projects.

Apart from building necessary technological capability, according to the report of the Alvey Committee another reason it was important to have a workable distinction between the Large Scale Demonstrators and the enabling technologies was, it was said, because the demonstrators were in a privileged position in that the industrial collaborators would receive the profits from the eventual exploitation. An important consideration for the policy planners was therefore to make sure that anything which might be considered enabling technology would not be caught up within demonstrator projects. The enabling technology was important to what Alvey referred to as the 'pre-competitive' stage of research. Pre-competitive was geared toward the production of enabling technologies. These would not necessarily be commercially salable products but would allow companies to have the resources for innovation to ensure national competitiveness. The pre-competitive stage was to be followed by the competitive stage.

Alvey, according to BEB's project management, did not wish to lose control over IKBS and its transfer to industry in general. This might happen if it stayed within a demonstrator project and in the hands of two companies. But IKBS was, of course, attractive to industry and BEB wanted to make sure it did not lose the potential commercial advantages it might offer them.

As far as BEB was concerned they had to make sure that the various parts, the likely contributions of each collaborator stayed together within the demonstrator. This system, they claimed, would consist almost entirely of existing hardware and software, and so could not be hived off into enabling technology. BEB could not, of course, be seen to be protecting IKBS for their own profit: 'Alvey is trying to alter our perception and transfer Manufacture from Design to enabling technology. They think they tell us what is enabling technology and we think we tell them.'

So it was important in respect of the Alvey guidelines that the Manufacture from Design project was seen to be application work when it was brought under scrutiny by Alvey. When BEB made an application for more money they were told by Alvey that there were insufficient funds within the demonstrator coffers; if they wanted more they would have to get it from enabling technology funds. That was seen by BEB management as Alvey's attempt to shift Cally's work on a designer system for the representation of design knowledge into the realm of enabling technology.

The task was therefore to be able to present the parts of the system as interrelated, that together they constituted an application of IKBS technology and that they only made sense if connected. Management played devil's advocate and role-played the possible responses that Alvey might raise against the designer system. It was becoming apparent that presenting Manufacture from Design as a demonstrator project was not foolproof; the role-playing going on made it evident that there was no clear-cut boundary. As far as the management, who represented the commercial interests of BEB, could see they could not provide a technical reason for the configuration: contributions/parts could just as easily be seen as enabling technology as they could be argued for demonstrator. Their role-playing tactic got the response, 'whose side are you on?' from some of the collaborators. To which management replied that it was not a question of taking sides, but of presenting a persuasive argument when they had to deal with the Alvey representative. According to management there was nothing to ensure that the system would not be hived off into enabling technology. The definition of the software was flexible according to where they wanted the funding to come from, but there was nothing that made it absolutely application technology in isolation from BEB's commercial considerations. Since they wanted all the work to be funded by Demonstrator funds they had to present the work as application technology. Their reasoning had a ring of commonsense circularity about it: 'It is because it is. It's all or nothing. We just tell Alvey they can't have it'. There was no scale or spectrum on which to measure the IKBS as applied or enabling technology: 'the representation of design knowledge is not for anyone else, it's for this project.' However, what they needed, management suggested, was an explanation 'more suited to Blunte's position than simply, "he can't have it".' Blunte was a member of the Alvey Directorate staff responsible for making sure that research aims were not mixed in with the goals of the demonstrator projects.

I don't how it was made to appear to Blunte as integrated through talk. It was, however, *agreed* that it was something that could not be settled, outside of practice: if when they did it it was proving to be research, fundamental and not yet ready for exploitation i.e not sure how turns out. But one rhetorical device was used to help sway the project on the side of demonstrator project: as a Cally member told me, 'Basically we lied to Blunte. We told him we'd make available for enabling technology anything that we considered research.' (What it means to make a 'technology available' is an interesting issue. In the context of this discussion it meant revealing enough about the research for others to work on but not enough that they could easily exploit it: and that centered on what representations were revealing, diagrams, code etc. In a later and different issue we will see that just what it meant to 'reveal' the technology was the subject of much interpretation.)

We have seen that BEB had their particular commercial reasons for classifying Manufacture from Design as a Large Scale Demonstrator. But did Cally also stand to gain from such a status? Jim Watson supported the view that the system should be a Large Scale Demonstrator. So when I asked him about this I was surprised to hear him say that Cally had more to gain - in other words, it was to their 'real' advantage - to be classified as enabling technology. To have classified the work as enabling technology was, Jim Watson explained to me, in their interests as academics. They could have spoken to others at conferences and they would be able to write papers and been a member of the Alvey IKBS club where they could have exchanged ideas with other academics. And Jim Watson could get his name known in the academic community.

Just as with BEB, however, the basis of Cally's cognition was not 'nature', 'science' or even existing technology. Rather the determinants of cognition were quite clearly social. The basis of cognition were *calculations*, made by Cally on the state of the current situation; did they stand to lose out by altering the co-operation between themselves and BEB? In other words was it to their advantage to stick with the decision for a Large Scale Demonstrator project? This is what Jim Watson asked himself. Having agreed to go along with BEB, Cally decided to remain in the Large Scale Demonstrator collaboration. If Cally had backed out in favour of getting enabling technology funds, Jim Watson argued, BEB may have withdrawn all support. In other words Cally may have been left without any project at all. There was also the question of future funding both with BEB and with others if Cally became known as an organization which retracted an initial collaboration. So what sort of 'choice' was it that Cally was faced with? Their calculations took into consideration their perceived ability to shape and mould the interests of BEB in line with their own. BEB, as Cally were aware, was the dominant industrial concern in the Alvey programme. And as had Peter pointed out, 'some would say that BEB was Alvey.'

This seems to say something about heterogeneous engineering. Cally were not breaking the agreement or rearranging existing relations to pursue what were their ideal academic interests. The question that this raises is what sort of model of human action do the network theorists work with? Do they take the view of rational action as pursuit of self-interest - the economists' definition of rational action? For the time being however it appeared to Jim Watson that BEB's commercial interests represented an unmalleable object which they would have to accept to have any funding at all.

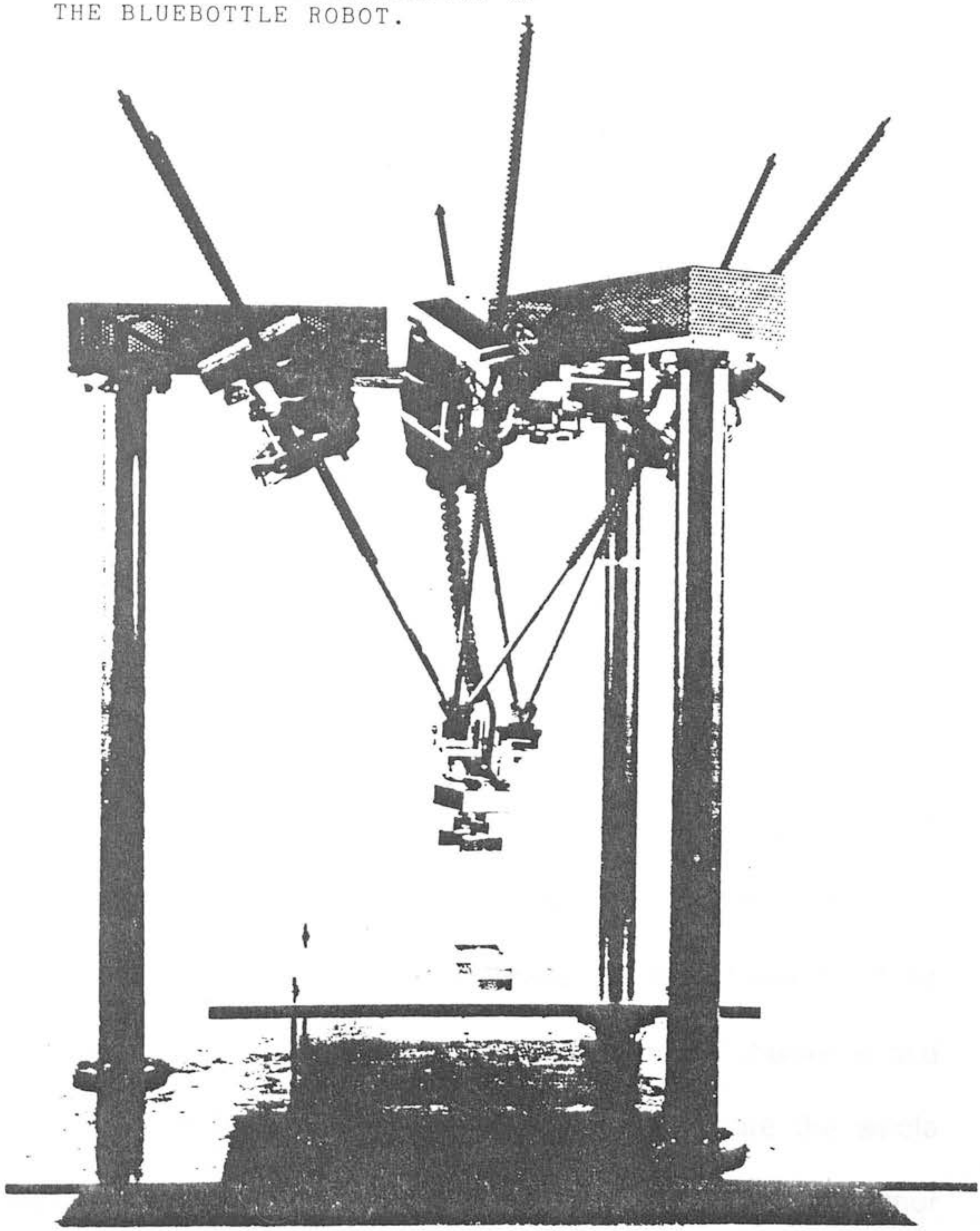
Within a matter of months then, the two-collaborator, 3-year long and non-commercial Design and Make project had grown with the help of some clever heterogeneous engineering and calculations into Manufacture from Design, an Alvey Large Scale Demonstrator project with some ten collaborators. This result was described by Crigbank as similar to 'making it with a wench. Both parties are concerned to find some mutual profit. Alvey got a good project and we got the money.'

<u>Constructing a Project for Alvey</u>

None of the Manufacture from Design collaborators ever advised me to read the Study Report to find out about the project. But since in the early days it was the only thing that adorned Cally's book shelves, which in turn was the only view from my desk, it made sense to give them a glance. In my early days on the project I not only thought that reading the Study Report would be useful for familiarising myself with what the collaborators were doing and the goals and aims of their work, but that it would also help me to be part of the team in some way. Instead it made me stick out like a sore thumb. Deen University's project manager, Joe Blair, was surprised to find me reading it: 'What are you reading that for?', he asked. 'It won't tell you anything', he added and laughed in the way people do when they feel sorry for your naïvety. Hadn't I noticed, he asked, that the way the work was now going, now that they were trying to do it, varied from the study report: 'We put it together to make it look integrated.' 'In actual fact', BEB Assembler's team manager, Nancy Thomas informed me 'we don't know how it goes together.' And neither, they said, did they know what they were doing. I asked if they thought I should stop reading the Study Report and they seemed to think that was a good idea because: 'You don't put your personal reasons for doing a piece of research in a proposal because you won't get funding for it.' So the Study Report did not list these individual reasons but suggested a widespread commitment to Computer Integrated Manufacture amongst the team: 'The contributors to this report believe that there is no more important application for advanced computer science than computer integrated manufacture.'

So what were some of the 'personal' reasons collaborators had for being in Manufacture from Design? The BEB Assemblers saw the Alvey project, according to Nancy Thomas as a way to prove the viability of their revolutionary robot. According to Thomas, when the research was done nobody else in the company (as a whole) was interested in this robot with the unusual structure. A place for it in a Large Scale Demonstrator project would represent a way to set it in context. It would provide an opportunity to do development work on the Bluebottle robot.

FIG. 4.5
THE PRESENT IMPLEMENTATION OF
THE BLUEBOTTLE ROBOT.



The project was looked upon by Deen University's project manager, Joe Blair, as a way to get some AI experience to bring to their work on geometric modelling: 'we don't want to extend modelling in the present way.' He pondered on whether it would be possible for individual research interests to be met within the broader context of the project. That, according to Joe Blair, was a goal that might not fit the aims of BEB as a commercial firm: 'BEB want a product and that could be a potential point of conflict. In modelling you might just make do with some 3-D straight surfaces in order to try out some vision work. But a commercial firm may step in and say they want curved surfaces because that is what will sell the system. That would hold back the original research goal to do something like vision work.' The result was what Blair called a bottom up project: each group doing there own piece of work but not quite sure how it fits together. But what is the broader context? Was there one? As far as Blair could see the project had no common theme; it had been composed bottom-up instead of top-down, where the whole is decomposed into its component parts. The issue whether Manufacture from Design was, technically and socially, a whole or a set of decomposable parts was, as we shall see a recurring one.

It seems perfectly reasonable therefore to see the Study Report as a dressing up of their work to meet the policy objectives of the Alvey programme for a coherent project with goals that had potential for pulling enabling technology. This, of course, raises questions about the success the Alvey programme would have in managing the project - of having its policy objectives met in practice.

Getting Started

It was no surprise to the project management that there were different interests in the project. It was perfectly reasonable, they thought, for collaborators in a joint project to fulfill some of these individual interests. But somehow they had to come together as a group to produce something. That would mean coming up with some sort of organization to combine both individual interests and the interests of the 'project' (see Olson, 1965). A speech by John F Kennedy was twisted into appropriate shape as a project motto: 'Think not what the project can do for you but what you can do for the project.' The collaborators would have to be organized, it was decided at an early workshop, in such a way that the work formed an interlocking chain of inputs and outputs. Each collaborating site would have to know what it was passing on and what it was receiving: a flow of expected technology on the basis of which each collaborator could make plans to crystallize the various pieces into a functioning whole.[3]

But to do this they would have to understand each other's work. This is part of knowing what they were doing, essential to building a team. Although I had been put right about the Study Report I assumed that at least some of the key terms would be 'familiar' to them: but it turned out that a 'technical' language which was totally incomprehensible to me was just as stupefying to some of the collaborators.

A recurrent phrase in the early days was: 'We have to understand one another.' They would have to understand what each other was talking about if they were going to build a system and if they were going to know who was doing what and how their work fitted in with that plan. Understanding the language was vital to having a dialogue: they had to know they understood each other. The unfamiliar language proved to be a way into the

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4 Crystal growing is not my description but their's.

project for me. I had expected to be the 'stranger' either in the sense of a curiosity or of being completely ignored. I had made an early attempt to make myself useful by sorting through and organising the files. If I could read them I would tidy them up a bit. I even offered to do some photocopying for them. Most of those attempts went by ignored. So I was taken by surprise when at last they had found some use for me. But I had not bargained on them seeing my technological ineptitude (as they saw it) as a useful attribute in their attempt to cohere as a group. This behaviour towards me was itself revealing about the project. It certainly gave a new meaning to 'acquiring native competence' - the importance of becoming part of the situation you observe. No one, I am sure, has said that participant observation is a static thing in the sense that it does not involve those you work with. But, at the same time, it was surprising to find out to just what extent my participant observation was a reflection of the state of the project, of the collaborators own native competences.

They saw my ignorance as an advantage in helping them standardize their technical terminology. While they might assume they understood one another, that would not be good enough. They had to *know* that they meant the same thing. They assumed that I would be clueless about the technology and that 'competence' was exactly what they were looking for. I could help them out, they said, by keeping a glossary of the terminology I did not understand and the terms that others said they were having difficulty with. They pointed out that it was not especially for my benefit that they were suggesting this but for their own. When I had built up enough, they suggested the list could be discussed at meetings. My notebooks were full of promise. How will the words get their definitions? Who will attempt to take control over definitions? What will be the relationship of the language to practice? Alas, at least for my purposes as an analyst, the question of 'definition', like many of the other questions raised in the course of the project, was by-passed rather than resolved. I never became the important 'keeper of the concepts' they had suggested!

The Cally Team

The project manager, Jim Watson, came to Manufacture from Design from a Cambridge software firm. Jim was smartly dressed, always in neatly ironed shirt and tie and carried an attaché case. Though Jim's role was central - he, for example, had responsibility for coordinating the work of Cally with the rest of the project - the group's inspiration was not him but an older member of the Cally AI Department, Peter Crigbank. Unlike Jim, Peter rarely wore his shirts ironed. It was a common joke on the team; 'Peter's taken his shirt straight from the washing-machine again.' They were not just creased but practically three-dimensional designs themselves. Or when his shirt looked less crumpled: 'Peter's fiancé must be back from the States.' It was assumed that Peter was not really capable of doing very much other than programming or, indeed, that he wanted to do very much other than programming. But his ideas and his programming were seen as crucial to the group's success. Everything was to be done to make sure it was possible for him to get on and do that. Lunches were often brought to an unexpected end by Peter's imaginary pressing of a computer keyboard at the lunch table: 'I must play twinkle fingers', he would announce before leaving.

Peter somehow needed taking care of and constantly reminded of where he was supposed to be at particular times. He never knew the time and would sometimes have to be phoned at home to remind him to get out of his bed in the morning for an important meeting. It would often be Helen, our secretary, who would do this. She was concerned about Peter's lack of interest in money. She told me how he did not know what he had in his pockets. Did he have enough, she would want to know if he was going out? Helen was affected by his moods. If she was sad she would say it was because things were not going well for Peter. And Helen worried greatly over her decision to leave the team: was she creating more trouble for them by doing that? They would have to interview others. 'Was she wasting their time?' she would ask me. But she felt that things would be in safe hands with Jim. He was 'very capable.' She treated us all like an extension of her own family; baking cakes and tarts for us at Easter and at Christmas (see Barker and Downing, 1985). Our secretaries were important to the functioning of the project and were always referred to as part of the team by Jim.

Often, however, it was not clear what precisely the secretaries were expected to do. Indeed sometimes Paula, Helen's replacement, got bored from having nothing to do since the team tended to do so much of their written work themselves on their own workstations. To relieve the boredom Paula would ask if she could type up my fieldnotes when there was nothing to do and she was bored. What she did like was when other collaborators came to Cally for meetings. Then she shopped for the buffet lunch and arranged the table. That kept her busy and kept boredom at bay. Another favourite was playing computer games at which she beat the researchers hands-down! Given that Helen treated the team like an extension of her family and that Peter was 'looked after' after by the secretaries, it does make one wonder about the role of the secretary in science and technology.[4] Are secretaries in science and technology there to 'feminize' the work environment and contribute towards the production of scientific and technological knowledge by supporting men in 'peculiarly "feminine" ways' as Barker and Downing suggest for the office? (Barker, et al., 1985) . An important aspect in employing Paula was, according to Peter, that 'she's pretty and doesn't wear too much make-up.' Other women interviewed for Helen's job had, I was told, shown more interest in what the team were doing and had asked questions about how a robot worked.

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[5] Delamont (1987) has commented on the role of the secretary in the production of scientific knowledge specifically in relation to getting papers out the door. This is part of her more general critique of social studies of science which have tended to ignore gender issues in the production of knowledge. This she has called a "blind spot".

The role of the secretary, however, was very important to my participant observation. In the beginning Peter and Jim would forget or just did not think to tell me about meetings. Helen would tell me if there was one in progress. To make it possible for me to join them she would take in a message or take the numbers for morning coffee. Paula was pleased to have me on the team, 'it's good having another girl around.'

Peter and Jim eventually shared a room in the new lab. Peter adorned his side of the room with a song by Winnie-the-Pooh. I had not expected to find, 'Isn't it Funny that Bears like Honey' on the wall of the chief investigator of an important demonstrator project or to hear him curse at his machine, '"Bother!" said Pooh', in the event of a programming error. On Peter's side there was also an abstract painting of a milk bottle and a photograph of a sailing boat. The team itself thought of Peter as a genuine eccentric. They told me how he had for a time driven a milk-float, believing it to be superior to the car in terms of pollution and safer with regard to speed. Safe that was, they told me, until Peter had crashed it into some railings! Jim, on the other hand, had one wall on his side of the room turned into a huge monthly wall-chart detailing his meetings with the other collaborators. His notes were stacked up on his desk and neatly kept in his brief case. Peter's were usually crumpled in his rucksack. Their notes were different too. Jim's were the minutes and agendas of meetings, Peter had lines of code and equations. Jim also kept in his drawer a tape recorder and tapes in preparation for his meetings with the other collaborators.

At a dinner party at Peter's home while everyone else sat around and spoke on such weighty subjects as Hofstader's book 'Gödel, Escher, Bach: the Eternal Golden Braid', Peter slept soundly in his chair: 'He's just like a little boy', his friend would remark. At social gatherings like this the number of topics that Jim would cover and give an opinion on was vast. Indeed whatever the subject raised he would have something to say about it. From art (Jim was especially keen on Escher) to music and politics, nothing escaped his interest or commentary.[5]

Sometimes Peter would roll down a mattress in the lab's spare room for a nap to refresh him for more time at the computer. Jim, on the other hand, never seemed to sleep. He

[6]Sherry Turkle has described AI researchers as "intellectual imperialists; with an encultured way of thinking on a global scale (Turkle, 1984).

explained to me how as a student he had made himself extend his day so he could work longer and longer: he would rise in the morning earlier, an hour at a time, and stay at work late into the night. Getting his PhD finished meant late hours and working out meticulously the six month schedule he had planned to have it finished in. He could chart exactly where he was on the road to completion. It was finished on the day! It might not have been the best PhD in structural engineering, he confessed, but it was done. Keeping on top of the work and the other collaborators meant Jim was always the first one at his desk at the start of each day to get some reading in before the deluge of phone calls from other collaborators would start coming in. He got in earlier than everyone else at first to play his tuba, but it turned out there was always something else to do, and so he never got any practice in. He also wanted to read AI books before the phone calls from other collaborators. In the afternoon, he ate a Mars Bar to get him through that point in the afternoon when he felt himself get weary.

The project would require careful management and Crigbank was not considered to be the best for that task. Helen, the project secretary, provided further proof that Crigbank was not to be entrusted with managing the project. She showed me where his files were interrupted with doodles of cats: 'That's when he gets bored.' And that was usually when he was at meetings which interrupted his programming.

Meetings like these were an opportunity to bring everyone together. But my period of observation was to be based largely at one site, Cally university. Part of having gone from being a small to being a large project was that it would involve many meetings with overall project management and the managers of each individual site. These people would meet regularly to discuss the direction of the project at what were called 'Technical Committee Meetings'. The Technical Committee Meetings were composed of each site manager who gathered under one roof and around the one table at BEB's London offices to discuss 'technical' issues: hardware, languages, availability of resources. But for participants there was often much debate at these meetings about what constituted both 'technical' issues and 'technical' argument. We can see this in the forthcoming chapters.

Jim was to attend these meetings, not Peter. Crigbank loved to travel around Britain on trains, but his place as Cally's principal chief investigator was to be with the team involved in programming. The meetings, despite their title, were 'social' in an important sense. Programmer Howard Jacobs saw an important part of Jim's work as project manager to 'keep management off their backs.' It was how Jim saw his work too - 'to make sure my guys don't get bothered.' However, both Jim and the programmers are, as Bruno Latour has argued (1987), 'doing technology', in the sense that the Cally team would not be free to program without Jim's careful negotiating with the other collaborators at Technical Committee Meetings. The minutes and agendas of meetings were Jim's domain - something which Craig Ward need know nothing about as he sat down to program in the Cally lab while Jim Watson took his place at a table to discuss 'the direction of the project'. (As we shall see in chapter 9 this division is more complicated than Latour suggests. Participants do not agree on what is the proper conduct of the site manager.) It was a division of labour between them that turned out to suit me. On the odd occasion Crigbank was required to travel to a meeting the experience, although good fun, was usually exhausting and nerve-racking. Crigbank was passionate about everything to do with trains: stations, timetables, the interweaving of the lines, their speed and most importantly that they represented a safe and hygienic means of travel. To him travelling by train was almost as exciting as programming. We did not always take the easiest route of getting from our meeting back to home. We would sometimes take old trains that were more like milk-floats before connecting with 'the flying banana', the high-speed Intercity. In a sense travelling with him was like being inside the black box of British rail. Running up and running down the stairs that connected platforms is what I remember in our bid to make some train or other. Since I was usually the one carrying the food (our breakfast on the first train of the day), knowing that Peter would never remember, I found the whole thing tiring. It was at times like these that I knew participant observation was more than an academic methodology, it was also a real job with its attendant train fatigue and shortness of breath. Since I was usually on a train travelling as far as London at least once every fortnight, I was very glad to be travelling with Jim Watson whose skills as a manager were reflected in his approach to travelling: well planned and comfortable. Travelling with Jim we did not have to know how many other routes we were connected to, we were on this train and that was taking us from A to B. So long as everything was functioning as it should be we were using the train system as I was sure it was intended to be, a convenience that you did not have to think about too much in order to use it.

But it was not just Crigbank's lack of managerial skills that confined him principally to the project. He was needed to help train those new members of the team who in the beginning were not familiar with AI.

When I arrived at Cally for the start of the project I was not stepping into a well-established team in the sense of a group of people who had worked together for a long time. Indeed I was surprised to find that after Crigbank and Jim Watson I was the next to appear on the scene. As I surveyed the departmental members' photographs, for a glimpse of whom I might be working with, I recognized only Peter's and Helen's picture amongst what were known as the 'mug-shots'.

Indeed at the beginning of the project we were still waiting on a place where the Cally team could work together. We awaited the refurbishment of the janitor's rooms in the attic of the AI department to become the workplace for the Cally team. Helen showed me around these rooms. With peeling wallpaper, rubble on the floor and the pictures of nude pin-ups it was hard to believe that this was to be the site of an important project.

But the hammers of the workmen were soon to transform these rooms into the clean white workspace for another set of 'workmen', the Manufacture from Design researchers whose tools were to be computers. Our furniture was 'officey'; smart swivel chairs, functional desks, push button 'phones and carpets. It was customary in the first few weeks for staff from the rest of the department to visit these neat quarters and comment on how smart it looked in comparison with their old desks and chairs in much drabber surroundings. As the peeling wallpaper and the pin-ups came down they were replaced by the block diagram of the possible system and a map of Britain. With pins stuck through the various locations of the other collaborators it looked like a military strategy map.

In the beginning I was moved between rooms, wherever a desk could be found. When I shared with Jim Watson (who himself was feeling it difficult to believe he was in charge of a project, as he was sharing an office with another member of the departmental staff until he was in the new lab with Peter) it was surprising to find him - in between making phone calls and writing letters to other collaborators - reading the same books about Artificial Intelligence as myself in an effort to learn about the subject!

When the rest of the team members started to arrive it was *me* who greeted them! Craig Ward was a newcomer who had been employed by the project for his background in mechanical engineering. One thing I certainly did not expect was to suggest which introductory books about AI he should read. However, Craig soon gave up after a few pages into Margaret Boden's classic, Artificial Intelligence and Natural Man (Boden, 1977) : 'Too much psychology for me'. In exchange he gave me some of his university notes on mechanical engineering and some text book material on design which he was using for his part in the project. I would find him alone in a room reading about the UNIX operating system and the AI language Prolog which would be used in the project. But he preferred 'hands on' experience and so together we would try first year undergraduate exercises in Prolog: nothing very complicated, just recognising the Prolog prompts and responding in the appropriate way.

This was not what I had expected: I was not 'observing', but acquiring some knowledge of AI at the same time as Craig and Jim. When it came time to learn programming, Craig was helped along by two more experienced team members, Tony Innes and Howard Jacobs. Just basic stuff, like how to write a program to find out on what days of the week Craig could expect to have dinner with the pop-singer Madonna: if it is Friday, Madonna is washing her hair and so the inference is that Madonna cannot have a dinner date with Craig.

There seemed to be a huge gulf between this sort of thing and the software that would make inferences about the dimensions, speed and other attributes of machined parts and then provide the instructions for their manufacture. Researcher Tony Innes seemed to have a similar idea. The project, he explained to Craig, was as fantastic as a Monty Python sketch about flying sheep. What did he mean? Keen on amateur dramatics (the reason he said he had a great time at Cambridge but left with a poor degree) and proud of the fact and joking that he probably had the loudest voice in the department, Tony wasted no time in giving us a fully animated and well-delivered explanation. He climbed onto his desk and began: 'There are two farmers in a field both watching the sheep of one farmer fall out of a tree top and plummet to their death. "Why are you doing that?" the other farmer asks. "Just think of the commercial pay-off if they ever fly," the other replied.'

For Tony Innes, then, the project was ambitious. He had little confidence in its chances of short-term 'commercial' success but, for That was what made it exciting for him: 'We should have Manufacture from Design team T-Shirts displaying flying sheep.' The chances of turning the diagram of a *possible* Manufacture from Design system that had graced the pages of the Study Report and which now hung on the wall of Craig's, Tony's and my temporary abode now seemed a remote although challenging goal.

Chapter Five

The Interweaving of the 'Technical' and the 'Microsocial'

Creating the Manufacture from Design project was of course more than collecting people and props together. They needed 'technology' with which to work. What happened, however, was not two separate series of 'social' and 'technical' decisions. As the 'new sociology of technology' suggests, the 'social' and the 'technical' were interwoven in the decisions and choices made in the attempt to create a working project (Law, 1984). Two examples - the choice of the computer and of its geometric software, show this most clearly.

The Computer Choice

A project like Manufacture from Design could go nowhere without hardware and software with which to program. BEB were pushing to have on the project a computer from their company, BEB computers. All the time they offered technical reasons for the advantages of the BEB computer over the DEC preferred by Cally. BEB computers were trying to get in on the lucrative civil computer market. They had been involved in defence computers and had failed to make any inroads in other markets for computers (Computing, November, 1985). If it could be used on the Alvey programme and on a high profile demonstrator project it would be a good advert for it. Developing a UNIX operating system for their machine would help them to get in on the market.

The BEB computer, BEB 54, was agreed to have lower performance than the competing DEC VAX. BEB claimed the 54's performance would shortly be improved to the necessary level. Basing a decision on expected performance which might not happen in the end, was however a risky business[1]. Cally could have reimplemented the software to run on the 54. As the project manager told me they could have, 'rewritten it in Prolog and Lisp'. But that was an inconvenience as far as they were concerned because it would take 'unnecessary' time.

But BEB were getting tired of discussing the computer in terms of its present technical capabilities. 'The sooner everyone

[1]The Cally team took the advice of one worker in the department who had worked in industry. He advised them never to accept conditions based on promises of future success without setting down milestones of what would have to be achieved within a certain time. In other words there should be a time limit on when to expect performance. This researcher had seen cases where a delivery date had been exceeded by more than a year. For Cally that could hold up their research plans.

realises this project is political the better', said BEB Machines site manager, Gordon Collins. It was the first time that the commercial interests of BEB had come into the argument. And that had been deliberate on BEB's part. The overall manager, Bill Wilkie, had 'been told to keep out' of his letters any mention of commercial reasons for the choice of the 54 in the hope of winning the argument on 'technical' grounds, either existing or promised. While they were discussing floating-point arithmetic speed and so on, Cally said they had believed there was a choice in the computer. With hindsight they felt the discussions had taken place in such a way as 'to make us think we had a choice.'

But BEB were also up against the interests of Reams. They did not share BEB's interest in the future of the BEB 54 and did not want to use a computer that might take so long to develop as to jeopardize getting their fuel pump out onto the market; they were committed to using the best available hardware and software for the job. BEB however had sent a letter out to the collaborators stating that if the 54 was not used the company, 'would have to reconsider its commercial reasons for being in the project.'

A resolution was agreed that satisfied the interests of all parties. It was agreed that the BEB 54 would eventually be used, and the collaborators reserved grant money to purchase it when given proof that it fulfilled certain requirements. In the meantime BEB signed an OEM agreement with another computer company to supply computer workstations for the project[2]. In fact the improved BEB 54 never appeared, but at least BEB had avoided the humilation of seeing a competing machine publicly adopted for a high-prestige research project it was involved in.

The decision to stall the purchase of the 54 was welcomed by Jim Watson: 'let's hope that's the political[3] behind us now and we can get on with the technical.' And he added for my benefit: 'I suppose that won't be much interest to you though.' I was becoming fond of the team and that comment made me feel guilty since they obviously did not welcome any more commercial concerns holding up the work or preventing them from using the system software they preferred. I did not want them thinking

[2]An OEM agreement refers to an agreement between an equipment supplier and a buyer, in this case the buyer was BEB, whereby the buyer is able to sell the original equipment on to a third party after they have combined it with other equipment or software, thereby having added value to the original product.

[3]This use of the term 'political' by participants, as a contrast to the 'technical' is discussed in (Mackenze, 1990).

that I enjoyed what so clearly infuriated them. But it was interesting that they saw me this way and drew their own assumptions about what my interests were. At the beginning of the debate when they themselves felt they had a technical choice Jim Watson assumed that I would not be interested in this. When the debate changed it was assumed that I would then be interested. It was a distinction with which I myself did not work. Nor was it a distinction with which Cally in practice worked as the case of the geometric modeller showed.

The geometric modeller.

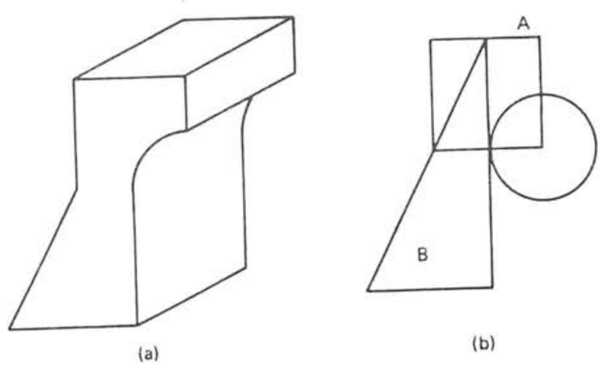
1. Representing shape in mechanical engineering design.

An important element in the design task is to represent shape. One way in which a design can take physical shape is in the form of a drawing. Since mechanical engineering deals with forming metal into parts of three dimensions a designer has to have a way of representing the geometry of those parts. Mechanical engineering is concerned with the representation of 3-D parts. Although drawing boards, paper and pencil are by no means outmoded, Computer Aided Design systems enables geometric modelling based upon the 'computer-compatible mathematical description of an object.' (Groover, & Zimmer, 1984, p.58)

2. Representing shape in the Manufacture from Design Project.

One of the aims of the Manufacture from Design project was to 'by-pass the engineering drawing.' (Financial Times, April 1983) That meant representing shape or the geometry of parts, using a computerized geometrical modeller. There are different types of modellers but the one for the project was selected to do Constructive Solid Geometry. This means that it represents shape in terms of primitives which are expressed in the mathematics of Boolean algebra. Those primitives, or basic simple shapes, can form a variety of more complex shapes depending on the Boolean relationship that is applied to them; AND, OR etc. This is illustrated in diagram 5. 1.

FIG. 5.1
BOOLEAN OPERATION C(A+B) PERFORMED ON
ELEMENTS IN B TO FORM SOLID IN A.



Quite clearly then, a modeller is at one level an abstract mathematical entity. However, the modeller was more than a mathematical representation for those involved in Manufacture from Design. What it meant to represent shape in a working system could not be treated in isolation from 'political' concerns that ranged from the legal to the commercial.

A team from the University of Deen was the collaborator that had been chosen to work on the modeller to represent the geometry of parts for the fuel pump. Cally had chosen to work with Deen since they 'thought they were good at modelling' and being a university Cally felt sure they 'would get along better' than if they were working with an industrial collaborator.

The Mapelle modeller was the software for modelling. Deen had worked on this in an industrial consortium called the 'Modelling Group'. It was the belief of management that Deen was bringing to the project not just their experience but the license to the modeller which would enable them to have access to the source code[4]. But Deen in fact did not have rights to the source

[4]'Source code' is the specific instructions which make up a program, in this case the modeller program. In order to incorporate existing programs with new ones, or

code of the modeller.[5] (That management could have slipped up on this was beyond the comprehension of many of the collaborators). This meant that the project had to get the Mapelle modeller from somewhere for Deen to work on for Manufacture from Design. The idea was to get the modeller from one of the collaborators of the industrial consortium with whom Deen university had worked to develop the modeller. But the conditions of such a license was that Manufacture from Design would not get access to the code of Mapelle. In other words the modeller was fixed. Work that the project wanted to do which could not be done by the modeller directly would have to be built around the modeller, treated as an unalterable black box, by constructing this as a 'shell'.

Any work that could not be done by Deen building a shell would have to be sent to the supplier of the modeller to ask them

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to develop their capabilities, as Deen were intending to develop the Mapelle modeller, it is necessary to have access to this source code.

[5]Another complication was that the researchers at Deen were split into two groups: one on the Alvey Manufacture from Design project the other on the Modelling group which was working on enhancements to the modeller. The Department of Trade and Industry (DTI) was funding both groups, but was not prepared to fund both to do what might turn out to be similar work. The idea was that they should work out between them what they intended to do. The results of either which might be needed by the other should not unreasonably be witheld.

to modify. BEB had wanted to purchase the Mapelle modeller from a BEB company BEB Computer Aided Engineering. This was believed by Cally to be because the company was in financial trouble[6]. Being a commercial concern, this company was prepared to make only those changes requested by Cally or Deen which fitted in with their own plans for the modeller.

The fixed nature of the modeller was something which concerned Jim Watson: 'If Mapelle is fixed then how does that affect what we can ask Deen to do?' And if that work required getting inside the modeller as opposed to building a shell around it here was no guarantee that what BEB might plan for its modeller or consider to be commercially viable would mesh with Cally's goals. As Jim Watson put it: 'It isn't straightforward that BEB would do everything that Deen asks them to do to Mapelle to help us. If all it did was help us in our problem and did nothing for BEB's present customers and made the package harder to

[6]There was another company which could have supplied the modeller. BEB believed they could control another BEB company more. However, it was the case that this BEB company which supplied computer aided engineering equipment, was in financial difficulties: '[BEB] slashes costs and cuts jobs...the company is sacking a tenth of its workforce... after a year of disastrous sales...the company had been hit by the slump in the electronics business and has had to cut operating costs... the computer aided engineering market is extremely cut-throat with a lot of aggressive US companies.' (Computing, November, 1985). I make no judgement as to which explanation of the decision is correct.

maintain then they wouldn't be interested because they get nothing out of it.' As far as Jim was concerned the situation was 'next to hopeless. I wouldn't expect necessarily that we would be asking for Mapelle developments that have relevance to BEB's present or projected customers. We are doing something different to the modeller.'

For Cally that was a concern, in that their own plans might be constrained by the existing capabilities of the modeller[7] and they would be unable to control the development of its future capabilities. Cally would have to build into the calculations for their future work the technical 'givens' of BEB. But these 'givens' might not be adequate. Jim Watson explained, 'We see how we want to use the modeller as distinct from how others want to use it. We are using Mapelle for questions of space occupancy, intersecting and calculating the minimum distance between two objects. In our designer system we don't want it for part programs.' [8]

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[7]As yet it was not known what it was that Mapelle could do or not in relation to Cally requirements, so in order to force a decision to be taken on the modeller Cally had been making use of an internal modeller on which to base an argument for discussion; we can get our modeller to do this can you get Mapelle to do it, if not then we should consider what modeller to get.

[8]Geometry data in manufacturing is useful for generating the information on how to make a part. To machine a part you need to know its shape and the path the tool

Using Mapelle for space occupancy, intersecting and the minimum distance between two objects was in essence closely related to the sort of requirements the Rapt assembly language would want to make of a modeller. An important element of Cally's work was, according to Jim Watson: 'to be able to send Rapt information to the modeller.' In current aids to design what was missing was knowledge about spatial relations.[9]

Why was the relationship between Rapt and the modeller so important and why might it be competing with the capabilities of a modeller that might be more in line with generating part programs? The Rapt work was the work of the robotics department at Cally, and that group had been key to Crigbank and to the formation of the project. As Crigbank once put it to me,'he was interested in getting an application for RAPT.' Crigbank and another key member of the robotics group were about to leave the

should go along to cut material. A part program automates the process by which the sequence of operations to be performed on a Numerically Controlled is planned and document

[9] On a visit to Reams designers I was shown something that was common practice - cardboard mock-ups constructed by designers from their engineering drawings in order to get a feel for the way parts were related to one another and if they were able to perform the function they were supposed to. It was older designers within the company who worked this way and who had kept these huge bits of cardboard like something from a school project. Designers who used the CAD systems were comparitively young.

department and Jim was keen that there should continue to be robotics research in the department.

The 'hole-in-the-surface'

How then could Jim Watson circumvent the potentially constraining influence which a modeller from BEB could put on the Cally work? A scenario which Jim worked out revealed that in attempting to come up with a 'technical' argument for another modeller (and in turn change the meaning of the modeller for the project) he intermingled 'technical' and 'political' issues in the style of the heterogeneous engineer (Law, 1984).

The other type of modeller was a Boundary modeller which represents shape in terms of all the surfaces which make up an object. Something which a boundary model could do more easily than Mapelle was the ability to put a hole in a particular surface. Although that can be done in a solid modeller it is much harder to find in a constructive solid geometry description where that surface is because it is not explicit in the representation: 'what you have to say is take this cylinder primitive from the other primitives that make up the models. But working out how you locate this cylinder such that it actually produces a hole in the surface is not trivial. It can be answered more easily in the boundary representation.' Such a technical argument was for Jim Watson a possible way of getting another modeller (which might be in technical terms more 'efficient') but which would, most importantly, let them out of a bind with BEB: 'BEB will consider modifications on a commercial basis and not on a research basis which is the basis of our work.'

But what about the supplier? Would another company not have the same commercial considerations as BEB in the light of asking for modification? Jim had thought about this and considered getting the modeller from a company where he knew the people - people he knew to have come from 'research'. But he had to be careful to secure the agreement of his Departmental Head, Professor Smith, who might be cautious about offending BEB. Smith was aware of the 'real world' in which, he said, AI workers now found themselves. As he said at one meeting, researchers could not expect to have everything their own way. They would have to learn to compromise. Jim noted: 'I would use the point about the boundary modeller as leverage if Professor Smith supported our move to question the modeller. But if he doesn't then we are faced with real problems.' If they had to go along with BEB and things didn't work out for Cally, 'I would let everyone know,' he threatened.

Chapter Six

What is Computer Integrated Manufacture?

How technically revolutionary should one be?

The formal definition of Manufacture from Design as a demonstration project, rather than enabling technology, by no means constrained what Cally team members actually did. Within the project there were competing definitions of what they should be doing, 'interpretative flexibility' (Pinch and Bijker, 1984) surrounded the content of the designer system. The key issue was how technically revolutionary Manufacture from Design should be. It would be a failure if seen as just another CAD/CAM system;[1] but it needed to be tied to existing work in such a way as to offer a hope of success. That, at least, was the vision of the team's central inspiration, Peter Crigbank.

Representing design knowledge

The Manufacture from Design concept, according to

[1] Computer Aided Design (CAD) produces a visual presentation of a design. It can be used to 'draw' and to modify drawings. Linking CAD with productive process, CAD/CAM (Computer Aided Manufacture) involves adding data about feeds and speeds of machining operations, for example, to the output of CAD terminals. The CAD systems are used to drive computer-numerically controlled (CNC) machine tools.

Crigbank, was an extension of work that had been done by a much respected colleague of Crigbank's, Ralph Slater. Slater had written an Artificially Intelligent program to prove the correctness of digital hardware design. This meant proving that the design of transistor circuitry would satisfy its specification; that it would behave as it was intended. Since AI is concerned with knowledge and intelligent behaviour it must use formalisms to represent knowledge (and intelligence) and use a formalism which is considered most appropriate to the knowledge being represented.

But what constitutes an adequate formalism for certain knowledge and its intelligent manipulation? 'Adequacy' could not be shown by pointing to a self-evident one-to-one, objective relationship between the representation and what was represented. Most significantly, Slater's work represented a credible past achievement. That Slater's program 'worked' justified the use of its formalism, according to Crigbank, as a way to encode the design knowledge relevant to Reams fuel pump. It 'had successfully proved the correctness of a straightforward but very detailed design, involving many thousands of transistors', Slater had written. As Slater had suggested, the design verification, apart from being of practical value, was also of great interest in terms of its AI research content. It involved representing the structure and function of complex systems, and knowledge about the problems the system was intended to deal with. An inference mechanism was needed to perform competently in a large search space. Techniques of guiding reasoning in search of a proof and general mathematical abilities like algebraic manipulation were needed, as well as understanding what the designs were intended to do.

According to Slater, the design process could be represented as a taxonomic hierarchy: a tree structure that allows a design to evolve in terms of inherited 'properties'. Taxonomies are a classic notion for the organization of knowledge. For example, students of biology are familiar with taxonomies as a way of describing the relationships between different species and 'their' types. A simple taxonomy might be:

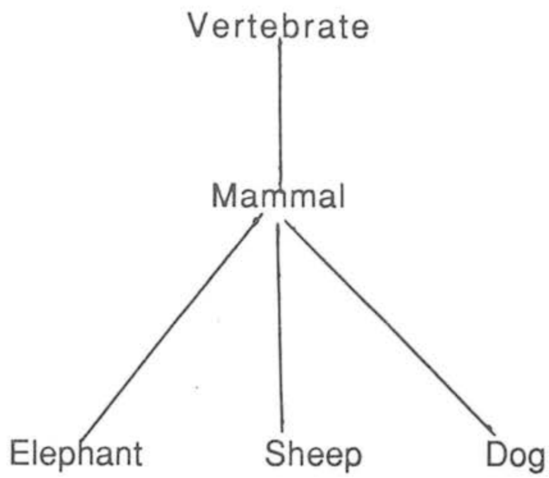

Figure 6.1

Source: (Shapiro, 1987, p.422)

This shows a hierarchy consisting of the class mammal, the superclass vertebrate, and the subclasses elephant, sheep and dog.

Of course, Slater's work was not concerned with the animal kingdom, but it did use these principles of organizing knowledge of the relationships between the different components that make up computer hardware; for example the relationships between multiplexers, registers, adders and counters. Slater's work was not immediately compatible with the problem which the Manufacture from Design project had set out to solve: bringing flexibility to the area of small-batch mechanical engineering.

Slater had dealt with the design verification of 2-D shapes of transistor circuitry. Robots, however, assembled the complex 3-D shapes of mechanical engineering as opposed to the laminated surfaces of digital hardware. Nevertheless, Crigbank felt that Slater's approach to 2-D could be extended to 3-D[2].

The Cally formalism was intended to support the evolution of a design. The evolution of a design is supported in terms of inheritance by a taxonomic hierarchy of engineering entities. These engineering entities are arranged in the hierarchy in what are called module classes. Modules are any engineering entity which has a concrete referent. This would then be used by designers to construct a design.

The idea behind the designer system was to represent, Peter said, what a human designer did. That meant that when a designer set about designing he proceeded from function. Hence the

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[2]Of course *how* and *why* work on 2-D design verification was extended to 3-D mechanical engineering design is an interesting question for the sociology of technology. Barnes (1982) states that the process of extending a paradigm to fit another situation (problem) involves the creativity of the scientist. The scientist *makes* one situation like another. In this case mechanical engineering 3-D design was made *analagous* to the verification of 2-D designs for transitor circuitry. But just what sort of process is involved in extending a paradigm? Unfortunately the period of my participant observation pre-dates a detailed analysis of this process.

taxonomy was a Functional Unit Module Taxonomy, becoming known as FUMT in the project. This is illustrated in Figure 6.2.

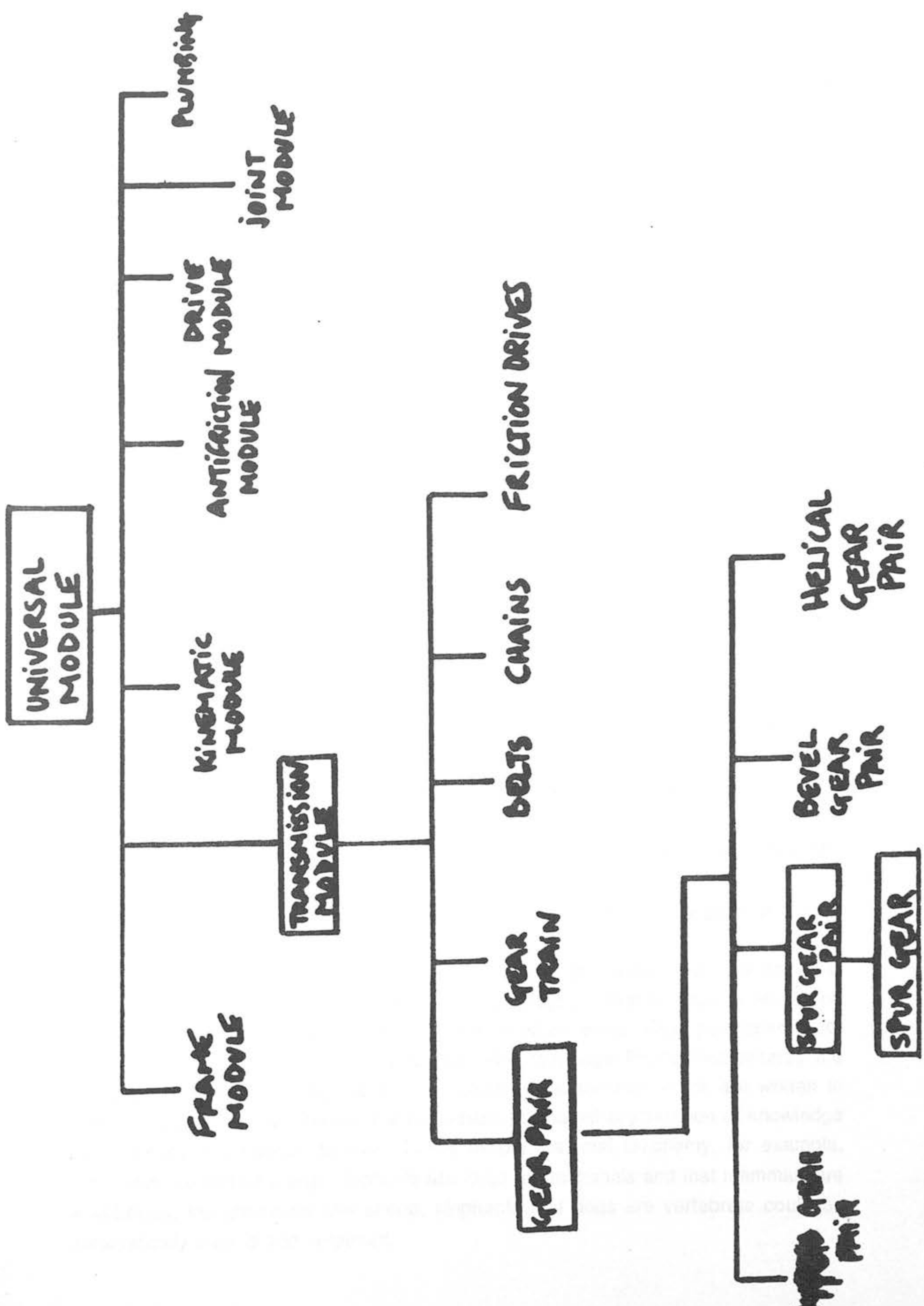


FIG. 6.2 A BLOCK DIAGRAM OF THE FUNCTIONAL UNIT MODULE TAXONOMY

For example, a transmission module would identify the function 'transmission', which means something that will take an output from a motor in terms of one particular form of energy and converts it into something like a shaft going around slowly. Modules contain the information about functionality as facts in the form of equations expressed in the programming language Prolog.[3]

This module would hold knowledge relevant to transmission, to turning this motion into that motion. But that would not tell us anything about what sort of actual device was needed for a particular component that will be required to work along side other components. So we need to specify the design even more, say, in terms of whether we want a hydraulic motor or an electric motor. And so to end up with a particular design, modules are arranged in the tree structure to progress from the

[3]Prolog is a 'logic programming' language based on first order predicate calculus. For any logic you can design a variety of 'proof systems', that is ways in which you derive new statements, or equations, from existing ones. One particular proof procedure is 'unification', and as a programming language Prolog incorporates the ability to automatically carry out this procedure for statements which are written in a specified syntax. This means it is compatible taxonomic organization of knowledge which Crigbank proposed to use. In the simple mammal taxonomy, for example, given statements that sheep, elephants and dogs are mammals and that mammals are vertebrates, the statement that sheep, elephants and dogs are vertebrate could be automatically infered and outputted.

most general at the 'top' -the root (it is an inverted tree!)- to the most specific at the bottom - the leaves - where enough information resides to make the design. The further down the hierarchy, the more knowledge is gathered that turns the specification for a design (expressed in terms of what function it is intended to serve) into a fully instantiated design; that is, enough knowledge is gathered that allows the design to be machined and assembled. The modules have all their values for the particular equations associated with them fully specified. The purpose of the design then is to arrive at a characterisation of modules, to get values for parameters. What made the designer system a novel approach to design, according to Crigbank, was that it attempted to integrate previously existing but separate software, like PRESS for algebraic manipulation, Rapt to derive spatial relationships and the modeller to derive shape information around the design of mechanically engineered components. The intended designer system was represented, by Jim Watson in the diagram shown in Figure 6.3 below. These different programs would be integrated using Poplog - a programming environment which supports (by providing editors and debugging facilities) the development and use of programs written in three different AI programming languages, POP11, Prolog and Lisp.

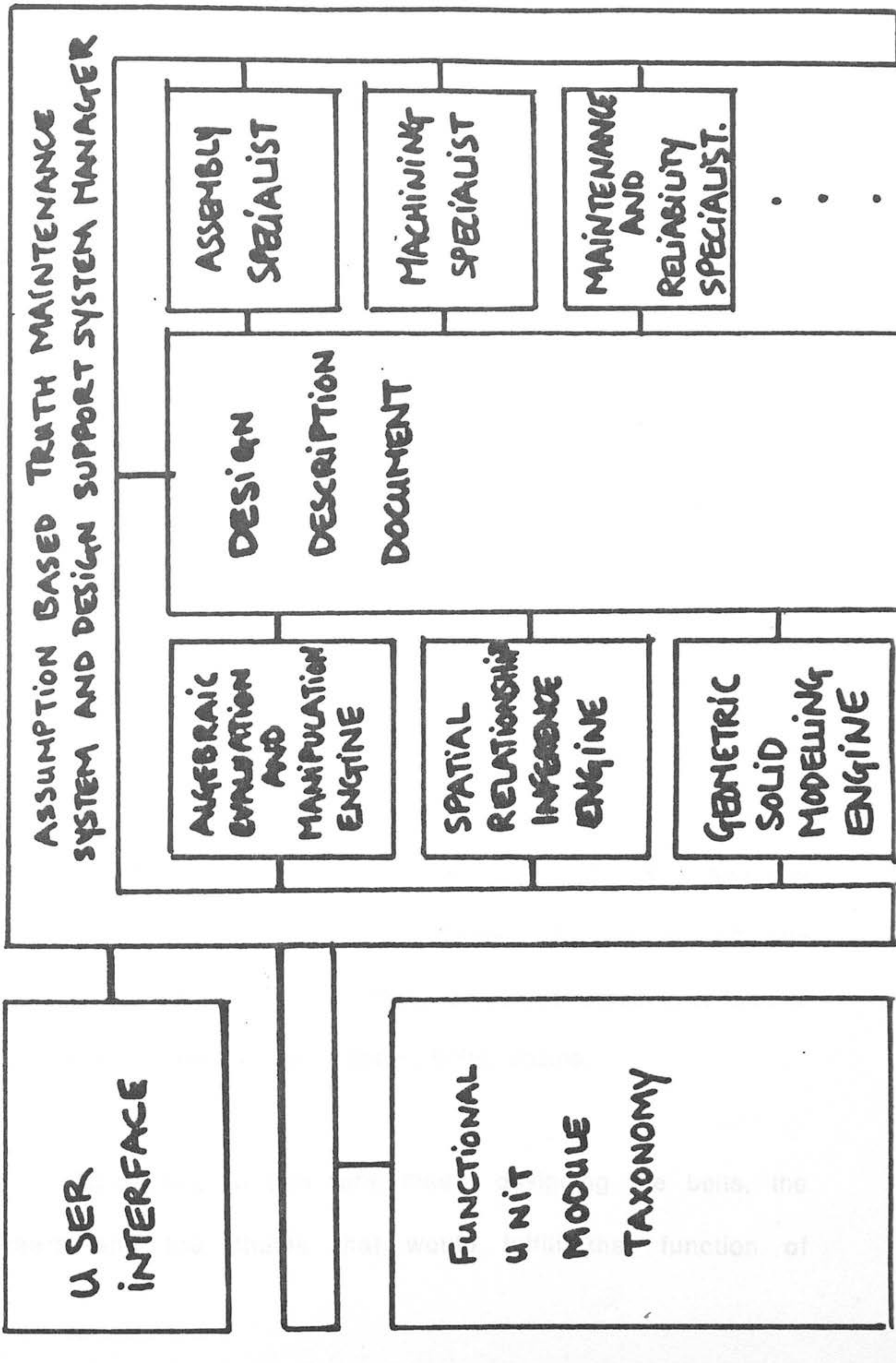


Figure 6.3. Block Diagram of the Designer System

To perform a function, objects have to be related to each other in space in order to fulfill that function. Since design, said Peter, was about objects going together, and RAPT was a language for talking about assembly - and assembly is about how things go together - then RAPT said Peter, represented a way of talking about design.

The combination of functionality and RAPT was, said Peter, what would distinguish a Designer System from existing CAD systems. Shape, claimed Peter, was related to functionality. CAD systems were concerned with geometry and representing shape, which they represent as dimensions, the position of points of lines in space. But CAD did not take into account, said Peter, the purpose that surface has, what it is intended to do. If you proceed from function, as the designer system does, then you identify that function - say, transmission The output from one module was the input to another, and you proceeded to a form to fulfill that function by using gears, belts, chains.

Proceeding to that form meant designing the belts, the gears and the chains that would fulfill that function of transmission. This is where the RAPT interpreter came in. RAPT derived the locations of modules from known relationships which existed between features of modules. Those features were represented in the modules in terms of shape information. The shape of modules in turn was represented by constructive solid geometry: that meant shapes were constructed out of primitive shapes (cubes, cylinders, etc) combined into the more complex shapes of engineering entities by Boolean algebra, as we saw in chapter five.

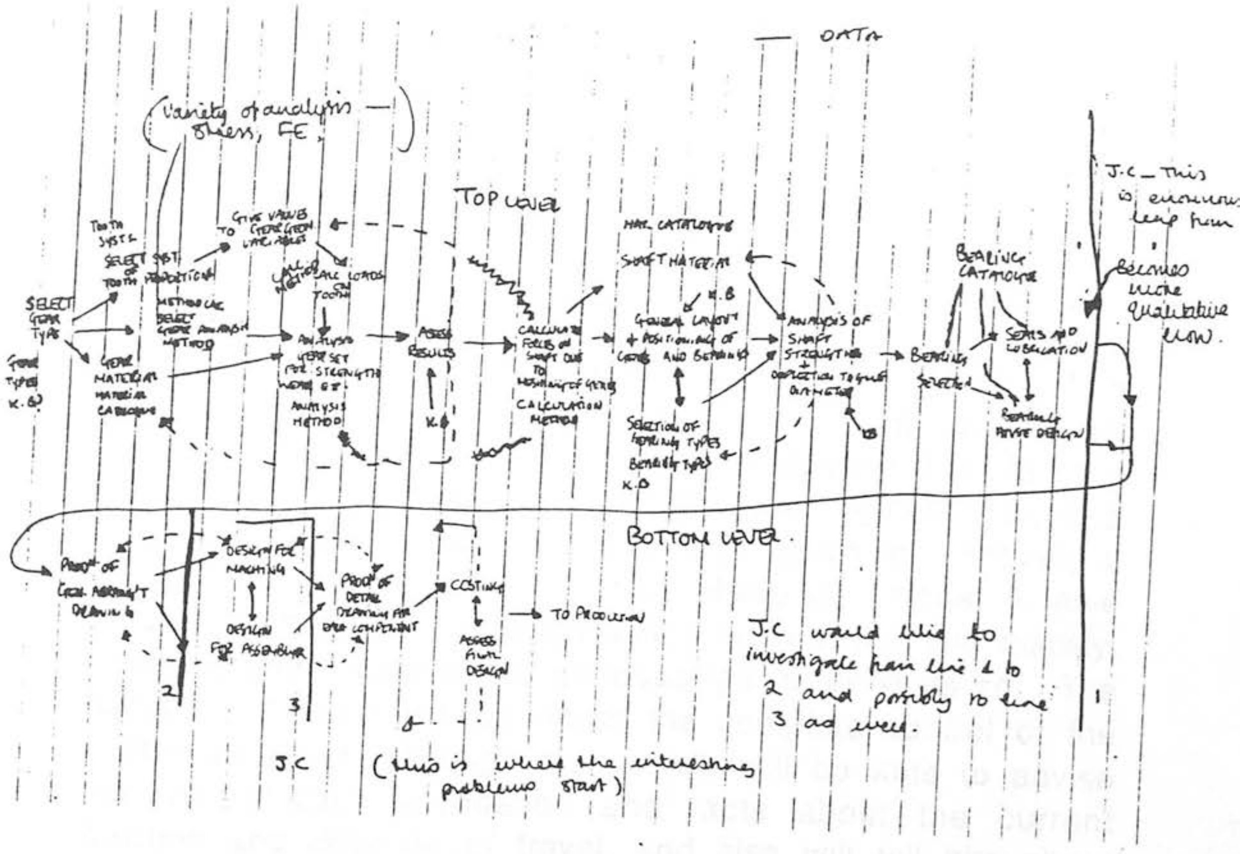
Features related to each other in order to fulfill a particular function. With a knowledge of how parts were related to one another, this representation was in Crigbank's opinion what made the system able to 'design' as opposed to merely 'draw'. The designer system, according to Crigbank, then 'knew' about shape; it 'knew' what was meant by a design. That meant that shape was not just a sequence of lines on a page to be interpreted for its functionality by, say, a production engineer, which is what CAD systems did (in this way CAD systems were no different from engineering drawings), but that they bore some significance in terms of their spatial relationships. For example, a journal on a shaft was not just a drawing of some lines which 'looked' like a relation between parts: it was a design of the functional relations between parts.

RAPT as a way to talk about design (to represent the task of designing) then was, said Peter, also a way integrating design and assembly processes. And crucially bringing together existing but previously separate software like Press, Rapt and modelling to work on design as represented by facts arranged in the functional unit module taxonomy was Computer-Integrated Manufacture, or CIM.

The Designer and the Machine

Another issue for the Cally team in designing the system concerned the relationship of the designer to the machine. This was to define the level of skill that a designer would require in order to use the system to design. A flow chart of a design process was drawn up, much of it from Craig Ward's university notes on mechanical engineering design, this is shown in figure 6.4.

FIG. 6.4
A FLOW CHART OF A DESIGN PROCESS.



In Crigbank and Watson's view the designer would go as far as the black line. Watson explained to his team: 'I think we have a reasonable idea of providing a lot of support to the left of the black line. The bottom level I don't think we know much about ... we're not trying to replace human expertise. We don't want to prevent the use of expertise by the human user.' The relationship that the designer would have to the system and the design process would be, wrote Watson, equivalent to a cyclist on a journey: the lie of the terrain was compared to the judgements that a designer would be expected to undertake in the course of designing. In Watson's view, these capabilities made the designer system similar to a bicycle in terms of the facilities it offered an engineer in design:

> 'The activity called engineering design involves the exploration of a design space [the Functional Unit Module Taxonomy]. Up to now the human designer has had to explore this design space on foot, aided perhaps by some specialized pieces of equipment, like a mountain climber has for the difficult parts of a mountain. The Designer System then is a vehicle for travelling around the design space in. Actually it is more like a bicycle. With this vehicle a designer is able to explore more of the design space more easily and quickly, having a better view of the surroundings as he does so. The direction of travel will be under the complete control of the human designer, although the vehicle will be able to advise him of relevant information and facts about the current position and direction of travel, and also will tell him about the shape of the local terrain. During the development of the

> Designer System there will probably be parts of the design space where it will not be able to go; places where the terrain is too rugged to drive over. At these places the human designer will have to get out (or off) and walk. This is why the Designer System is a bicycle and not a car, so that it can be carried over the fences, or pushed up the hills.'

It was this aspect of the designer system which in Watson's view made it a 'designer's apprentice'. He explained what this meant:

> 'This term emphasises the fact that we are not aiming to replace the expertise of the human designer, but rather to improve and extend the tools he uses to design with. Put another way the Designer System should increase the productivity of a good designer but not turn a bad designer into a good one. It will therefore be able to carry out the tedious and repetitive tasks quickly.'

<u>The Virtues of Flying Sheep</u>

In a team brought together for the first time, with a range of backgrounds and views about what Artificial Intelligence should be, these aims - extending a 2-D formulation to 3-D, and assisting rather than replacing the human designer - were by no means immediately acceptable to all members.

Tony Innes' tale of the 'flying sheep' had been accompanied by a flightless jump from his desk. Tony was enthusiastic about the latest work going on in AI and was the only one to circulate the very latest offerings from the journals to the rest of the group. These included everything from the latest in design, a hot subject in AI, to how to establish relationships between industrialists and university researchers. He read widely on up-to-date things; the latest books on expert systems to the businessperson's bible on how to succeed in business, 'In Search of Excellence'. Tony liked being part of the AI scene. He was always preparing papers for some conference or other and never seemed to be off the phone discussing amendments to papers he was co-writing. He was certainly the team's most dynamic member. An idea for a paper could turn up at the most unexpected moments and places, he said. His latest paper had been the result of coffee-time chats with colleagues. I spent much time making myself useful by taking messages for Tony or photocopying some article he wanted to circulate to the team.

Tony Innes's scenario of 'flying sheep' presented the picture of a potentially unattainable technological goal and artefact. But that was what made it interesting for him. It was, in his opinion, 'beyond the state-of-the-art' research. And the Manufacture from Design project he saw as an opportunity to use the resources of Alvey, both in terms of time and money, to do some 'beyond the state-of-the-art' research. The little confidence he had in its chances of success, as exemplified by the 'Flying Sheep' scenario, was what made it a project worth taking on. He looked forward to the team's first meeting to discuss the designer system to air his plans, where he said, 'We should be tackling hard problems we don't know how to solve.' 'We should be looking beyond the next five years.'

But the work that Tony had planned for the designer system to advance the state-of-the-art in computer aided design and manufacture did not sit easily with what Crigbank and Watson had in mind. The work that Tony had planned was almost immediately seen as something which might jeopardize the viability of the Manufacture from Design concept. The goal of the first, pilot, stage of the Manufacture from Design project, was to prove the viability of the Manufacture from Design concept, and that could be threatened by an over-ambitious version of what that concept was. Some of the dialogue between Watson and Innes was as follows:

Innes: 'What will the Pilot project consist in?'
Watson: 'Building in knowledge.'
Innes: 'Then it is an expert system.'
Watson: 'No its not! It is a designer system.'
Innes: 'Then it is not worth its salt!'

> Watson: 'Are you saying we won't be demonstrating an intelligent system?'
> Innes: 'Yes!'

Innes did not disagree that Crigbank's work was extending Slater's formalism. What he did feel, however, was that this was not the best way to proceed. That the designer system was to integrate previously distinct pieces of software was not, according to Tony Innes, going to be sufficient to distinguish it from existing CAD systems on the market. Indeed, using these resources would limit the designer system in assisting skilled designers, Innes felt. There was nothing new about inheritance hierarchies, he said. They had been around a long time. The system would not be a design aid to already good designers, but should be trying to turn average or below average designers into good ones, not by teaching them buy by building a system capable of qualitative reasoning and reasoning with uncertainty. Tony explained that,

> 'Jim is wanting to do things that have already been done. I mean Peter's work - people have been working on that for ten years. Functional hierarchy in Prolog in not new. I really don't think there is much IKBS in getting the various engines like Press to talk to one another in Poplog in a UNIX operating system. Jim has a short-term view of the system. We should be tackling hard problems that we don't know how to solve. We should be looking ahead five years and not reinventing the wheel.' [4]

What they could be doing in the project, Tony argued, was building a system that included a number of analysis packages and knowledge bases which would 'know when to come in to deal with design.' The packages, argued Innes, would 'know' when their expertise was need to help solve a problem. It was, he said, similar to a board meeting, 'with everybody sitting around a table, if the issue of finance is raised the accountant says, "I know about this," and comes into the discussion. He is turn might mention sales and so the marketing person comes in'.

As it was there was nothing in the description of the designer system in the Study Report which would make Tony himself, 'want to go out and buy it.' And as for the idea of the designer system providing capabilities analogous to the bicycle: 'shouldn't we be trying to take chunks out of heads and put it into the machine'[5], said Howard Jacobs in support of Tony. Watson replied 'I don't like that... we don't know how to do that.' But

[4]It is interesting to note that one associate of Innes' claimed that concerning work on qualitative reasoning: 'we do not expect to see many application papers presented at Expert System conferences in the near future which are built from qualitative models - we do hope, however, to see more papers on theoretical work in this area.' Expert System 85 (ed.) M. Herns.

[5]Forsythe (, 1987) discusses the way AI workers treat knowledge: 'For knowledge engineers, knowledge is apparently a 'thing' that can be extracted like a mineral or a diseased tooth.' (p.9)

Jacobs claimed: 'We are attempting to codify expertise and take decision making for the designer.' Watson disagreed: 'We are codifying knowledge not expertise. Expertise is how you do something.' They were providing a tool to the user, said Watson, and advice which the designer could choose to use.

Watson also felt that attempting to make the project too ambitious, could lead to over-inflated expectations which might lead to accusations of failure: 'If people think we are attempting this they will expect us to do it'. AI was, after all, on the verge of regaining some credibility. What they did know, said Crigbank, was that Slater's formalism was a tried and tested method.

Crigbank had faith that the wall diagram would come off the wall.[6] They had, Crigbank explained while looking at a diagram of the contributions, more or less, all the various elements for what was necessary to turn this layout of a possible Manufacture

[6]Crigbank's confidence was not shared by other researchers within the department who were not involved in the project. One worker told me that he doubted the possiblity of buiding such a system: 'It's way beyond the state-of-the-art. It would be like giving your car to a garage and it came out fixed at the other end and you didn't know what tools had been used on it. It seems like it is only those who have been involved in its construction, in the idea of the system who believe in it. All I think they can do is prove the feasiblility of the concept. At the end of the pilot or demonstrator phase they will say, "it's possible to do this or it's not possible to do this."'

from Design system into a working one. To Jim Watson, as project manager, this was an important consideration. He was very conscious of the limited time they had to prove the project's viability: 'How do we provide verification for what we've done? We want to say that what we've said we'd do, we have done.'

In answer to this it was Tony's view, that instead of providing verification they should be aiming at a hard experiment. At the end of the five years, he explained, that experiment could be shown to have either failed or succeeded. And Innes believed that it was the technologists who should decide what research should and could be tackled and what could be expected.

Getting allies behind him would not be easy for Tony. Could he get pressure put on Crigbank to change his mind about what they should be trying to do? Craig Ward was new and unfamiliar to AI: he could, he said, see both sides. In the room he shared with Craig, Howard and myself, Tony would air his views. Peter's position he felt had been strengthened by what he saw as Jim's sycophancy: 'Everytime Peter opens his mouth, Jim nods his head. He agrees with everything he says. It's so annoying.' Tony corrected me when I asked him about the system's knowledge base: 'Let's just call it a database', he answered and then continued to Craig, 'The fundamental problem is if we are working on electronic catalogue. What are we proving by punching in three pages of a bearing catalogue. Pretty intelligent stuff, eh?' he said sarcastically. 'Are we having the user type in this bloody stuff? Where is the IKBS in that?'

As for the term 'apprentice' which Jim had used to describe the designer system, that was another point of contention with Innes. The term 'apprentice', Tony told Jim, suggested a system that would learn form a master, in this case the engineer. The idea being that the master would transmit the relevant knowledge to the apprentice. Since the designer system was for Tony regrettably more conservative in its aims in not permitting the machine to take on more of the qualitative aspects of design, it was not an 'apprentice' but an 'assistant'. On this point Tony added to Craig, 'We should be telling designers what pages of that catalogue to go to, not giving it to them to flick through.'

Both Innes and Watson spoke of how they fell into Radical and Conservative camps. Watson explained: 'There is some conflict on the group. Some think that it is too conservative. I think they are aiming too high.' It was a division about which Peter had made his own assessment. On one of our train journeys together he told me how Innes' outlook could partly be put down to the enthusiasm of youth[7].

One of Innes ideas was accepted by the rest of the team. The FUMT, described above, represented what Cally referred to as, the space of possible designs which could be inferred from the encoded design knowledge it contained. Design, said Peter, was all about exploration in a large space of possible designs. In this process logical consistency of different statements about different aspects of the design is very important. The most usual form of maintaining logically consistent statements in AI, or what is known as 'truth maintenance', is done by a method called backward changing. It was Tony Innes who introduced to the project another form of maintaining truth: it was based on the 'Assumption Based Truth Maintenance System' (ABTMS) of de

[7]After project meetings, when the direction of the designer system was discussed, however, Jim Watson could not be entirely sure that there *were* different points of view within the team: 'Perhaps different language makes one assume that different concepts are being discussed'. This could also be seen perhaps, as an instance of the "methodological malaise" which AI was supposed to be suffering from, according to Alan Bundy.

Kleer and was called 'Choices without Backtracking'. Jim Watson did not immediately accept Tony's suggestion. But Crigbank saw it as a way of letting the designer create a design in an infinitely large search space. And most importantly what it enabled, said Peter was a way of 'getting some 1985 AI into the project'. What the ABTMS did was to allow the designer to 'play about' and change his mind about design decisions, for example, when a different value for a gear speed was chosen all the work based on that decision was not wiped out as it would have been when back tracking truth maintenance was used, and this meant that a designer who wished to revert to the old design decision could do so without having to redo the work. The ABTMS was said to be like a record-keeping system, and all the inconsistencies are collected together in a 'no good assumption set'. It would keep track of all the dependencies that a designer would normally have to remember. In a final design, however, the set would have to be 'good'. This meant that a designer who changed his mind from one gear speed to another would eventually have to chose which was to be the one for the design in hand. The ABTMS would allow the designer, Watson eventually conceded, 'constraint-free-exploration' of the design space; or what Crigbank called, creativity, by not enforcing 'truth' consistency on the design until the designer had tried various possibilities. And that was something, said Jim Watson, 'We just think designers would like to have. It's what I would like to have if I was a designer'.

However, despite this achievement, the Manufacture from Design project was not, Tony Innes claimed, going to do his career any good especially in terms of getting papers out. As his radical vision for it faded, he seemed to pursue his outside contacts even more; arranging more meetings and conference papers. He began to arrive for work later in the morning and started leaving earlier at night: 'I've got work to do at home', he would say. He had not, he told Craig and myself, come to Cally 'to do a hacker's job', which is what he believed getting the various programs like Press, Rapt, modeller to talk to one another in Poplog to be. He certainly did not want to stay beyond his contract and eventually left for Hewlett-Packard.

How socially revolutionary should one be?

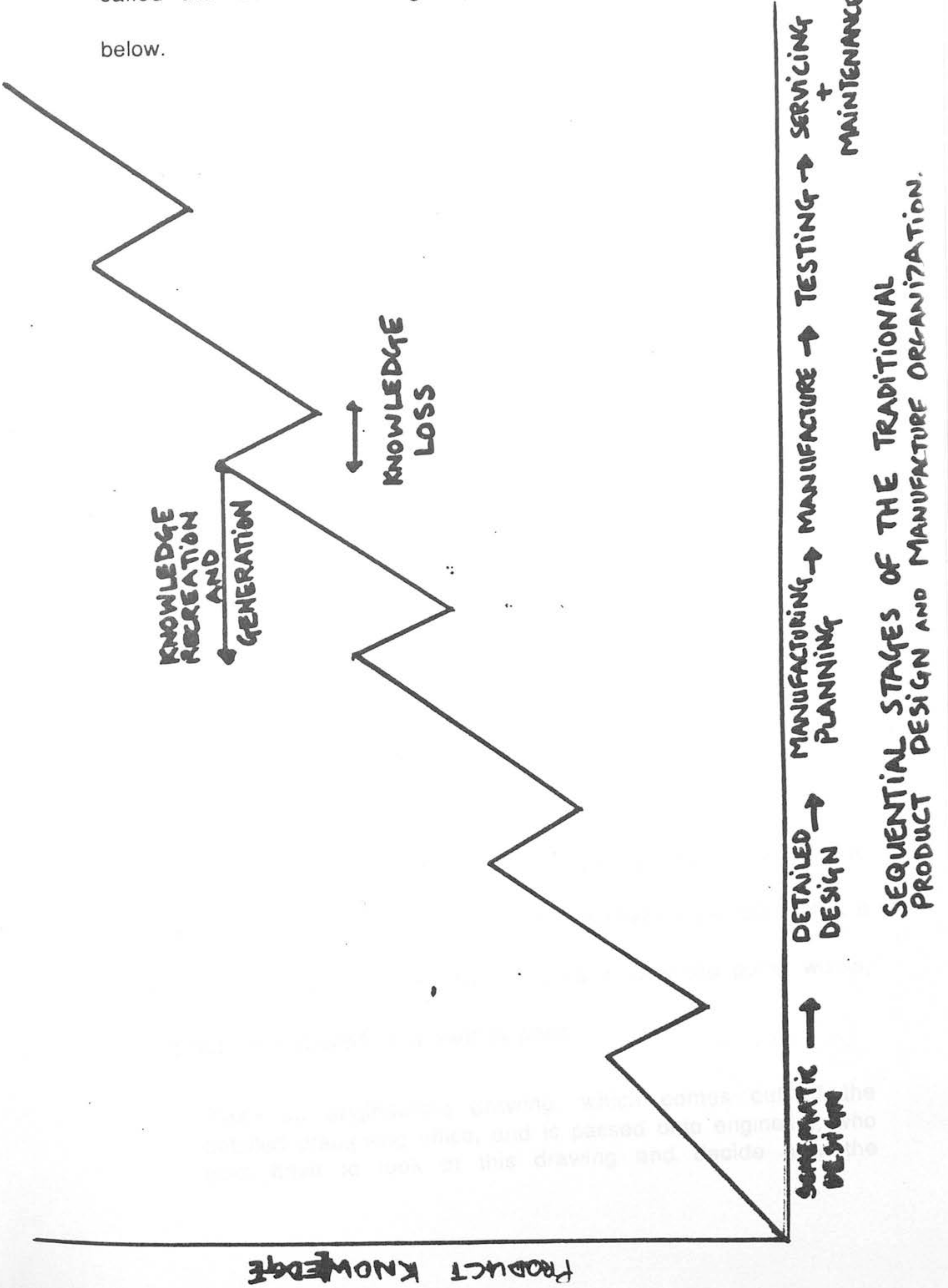
The different meanings which Innes and Crigbank attached to the content of the designer system were not informed in their conversation, within the Cally lab, by a macro-problem. It was Jim Watson as project manager who associated the work that was to be done on the workstations within the Cally lab to a problem in manufacturing industry. Crigbank did not do that sort of thing. It was the same with the Design and Make proposal. David Curtis had written the piece on computer-integrated manufacture that served as that proposal's wider rationale. Jim sought to locate the project in terms of the inadequacy of the engineering drawing as a means for 'communicating the design intention to manufacturing, inspection, toolroom, construction and other departments. Drawings indicate what has to be done to produce the product and make it work' (Cooley, 1981,p.51). The sequential organization - that is the design stage followed by draughting, followed by machining information, followed by assembly and then maintenance data - depends on people to interpret drawings and to pass that information onto others down the line.

According to Jim, that system worked, 'but only because people are very good at handling knowledge in informal ways ... But there comes a point where you really cannot really improve the flexibility of this system because we are using people in this way as well as we can.'[8] According to Jim, as this knowledge got passed on some vital elements got lost or redistributed throughout the organisation. A production engineer not sure about some information will have to talk to someone further back in the chain: 'Such conversations do happen, of course, but the way most manufacturing companies are organised does nothing to encourage them.'

It was, said Jim, endemic to a process where people used different conventions that they would make mistakes. They could not be expected to handle the inconsistencies in knowledge forever. The world of engineering drawings, machine tools and the programs to run them, swarf, production plans, break downs, queues of parts-in-progress and the effort of people to handle that complicated world was, according to Cally, at the same time a world where knowledge was created and then lost again. It was said Jim a bit like Chinese whispers. The original information could end up distorted, what started out as the command: 'Going to advance, send reinforcements' could wind up as 'Going to a dance, send three and fourpence'. It was a scenario which Jim Watson illustrated for the world of manufacturing with what he

[8]Jim Watson's interview with Computing, 1986

called the 'Saw-Tooth' diagram, which is shown in figure 6.5 below.



The saw-tooth diagram illustrated what happened when knowledge was being mishandled. The 'jagged-edge' highlighted the point at which people and machines, notations and diagrams, software and hardware failed to converge. A popular story within the group was used to illustrate the point. It was told to them by David Curtis and it concerned the case of a designer who passed his engineering drawing annotated with 'N/B' onto the production engineer. But 'N/B' did not mean the same thing to the two engineers. The designer had put it in as an instruction to the engineer, shorthand for 'Nota Bene' and in this case meant 'Take note of this equation, it is important.' The engineer however had taken 'N/B' to mean 'Make this component up in Naval Brass.' Naval Brass is an extremely expensive material, and the result of course was a serious and costly error.

An engineering drawing of something like a fuel pump leaves much unsaid, Jim claimed. An engineer must infer what it does not explicitly communicate - including how the pump works, and the roles played by it various parts:

> 'Take an engineering drawing, which comes out of the detailed draughting office, and is passed onto engineers, who then have to look at this drawing and decide how the

> components on it are to be made. That engineering drawing, which may meet all the standards of engineering drawings, does not explicitly represent the functionality of that component...someone looking at the drawing has to work out what each part is and what it is meant to do. Now skilled engineers are perfectly capable of doing this. But there may come points where, because it is not explicitly represented, you cannot guarantee that you are understanding completely what this component is for.'

But, said Jim, the designer system's representation of functional knowledge was what would enable design information to be created and handled explicitly and hence consistently. The key obstacle to flexibility in manufacture, said Jim, was a problem, which others had failed to tackle, associated with the distribution of knowledge in the factory. Achieving consistency on the knowledge that was generated in the manufacturing process was essential.

The system as planned by Jim and Peter was viewed, as we have seen, by Tony Innes to be technically conservative. But how did this view of the technology meet with the goals of the other collaborators? Was this also the route to flexibility and Computer Integrated Manufacture as envisaged by the industrial collaborators? BEB's manager Alan Rogers did consider the creation of knowledge to be a problem facing manufacturing.

Indeed, he had written an article for the BEB company journal explaining that flexibility in manufacturing depended on all parts of an organization knowing what was going on so that the manufacturing process as a whole could respond quickly to changes in the market: for example, a cancelled order or the quick re-routing of a batch due to break-downs in machinery. But for Jim Watson the concept behind the designer system was 'heretical'. For the Manufacture from Design system to work outside the lab it would require, Jim claimed, changes in the social world. Creating consistent knowledge was not just about writing lines of computer code - it would also involve 'social engineering', as we shall see in chapter seven.

Chapter Seven

How centralized should you be?

Macrosocial centralization

Project manager, Jim Watson associated the problem of knowledge gain and loss with another issue affecting manufacturing industry - the 'accountancy lag'.

It was becoming widely recognised that existing methods of accounting were lagging behind the needs of modern manufacturing. In the United States, the National Academy of Sciences Committee on Computer Aided Manufacturing Annual Report, 1979 noted that: 'The application of existing evaluation techniques to new manufacturing technologies results in an underestimate of the benefits. No method currently accounts for the benefits resulting from integration and reorganisation' (quoted in Senker, 1986, pp. 17-18). 'Old fashioned analyses' were said to 'scupper modern manufacturing' (Financial Times, 1986). New technologies were being evaluated according to the payback method which it was claimed ignored new standards of measuring manufacturing performance suited to new technology.

Using the payback method of investment appraisal each department in a company calculates the cost of a particular investment in terms of financial payback, that is return on capital. The appraisals are then sent to top management for approval. According to this method management approves those investments which will repay their costs within a specified period, usually two to three years. The payback method has a built in safeguard against risk. However, these methods were said to be a 'Barrier to Strategic Investment' in automation technology' (Senker, 1986, p.17). 'The accountant ignores them which leads to an "accountancy lag". As a result, companies needlessly delay or cancel decisions on reinvestment.' (Financial Times, 1986). The Technology Policy Board's document (1980,1985) on the 'Way Ahead' for the management of manufacturing technology agreed that conventional accounting did not properly evaluate the benefits of new flexible manufacturing systems. But any changes were said to depend on having a dynamic Board of Directors at the head of a company. Others, for example Senker (1986) suggested that top management personnel to be trained in computer aided manufacturing technologies in order to better assess the advantages.

Jim Watson spoke about accounting to eminent visitors to Cally like Eugene Merchant, research director of Cincinnati Milacron - the largest machine tool builder in the US. Merchant agreed that existing methods were not suitable to new technologies. Jim spoke of how 'outmoded' practices could affect the decision to invest in new technology like the Manufacturing from Design system. I thought that accounting was just another subject for Jim like art, music, politics or films about which he spoke with us (the Cally team) in the pub or at a meal. But on accountancy he spoke with almost messianic zeal. In Jim's scenario there would be no waiting around for accounting methods to catch up with the 'needs' of manufacturing, for top management to be trained in new technology or for a dynamic Board of Directors to appear on the scene, in order for a valid assessment of the designer system to be made.

Rather, Jim's scenario for designer system reversed how the 'problem' should be seen. The designer system was, he claimed, a new technology which was at the same time the *solution* to the problems engendered by traditional accountancy. In this scenario, accountancy problems were solved by the way knowledge was created and handled in the designer system. For the designer system to work changes were required in the social world. The knowledge for assessing new technology had to be handled by a new set of practitioners.[1]

The knowledge which the designer system made available to designers would, said Watson, put <u>them</u> in the position of being able to make decisions about what projects to take on board. They would have the information at their finger-tips, as a result of having created consistent knowledge, and, on that basis be equipped to assess the profitability of a project. Because they would have complete knowledge they would reduce the safety-factors used currently by accountants to compensate for having incomplete knowledge in assessing contracts. As a result of accurate knowledge it would be possible for a company to take on more contracts and in turn, Jim argued, increase overall profits. But all that was a process which called for some social engineering: a reversal of the previous status held between accountants and designers within manufacturing industry. The

[1] Jim Watson took a similar stance with politicians. It should be AI programs that take decisions about government. Amongst a group of socially concerned computer scientists; concerned about AI and jobs and skills and to get the opinions of people about these systems Jim said it was up to the AI community to educate people about AI. The others considered this to be an arrogant attitude and approach.

central role of the designer system as Cally saw their work in the project would lead to and be reflected by a change in the status of designers within the enterprise. The practitioners of 'accounting' were to be the designers. In this scenario new manufacturing technology was not a passive object awaiting changes in the 'outside' world (the social context of accounting). The solution to the 'accountancy lag' was built into the knowledge representation schema of the designer system[2].

According to Watson the 'savings and efficiency improvements sought by the Procrustean domination of financial control' (the accountants) was a situation that was 'forced on manufacturing by the inherent difficulties of the existing organizations in handling the knowledge generation process.' In other words it was the pass-oriented nature of knowledge that was responsible for the problems in evaluating the expected

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[2]Senker (1986) suggests that engineers should play a more important role in strategic decision making than they do at present in the UK. He also acknowledges that this would 'pose a threat to other managment functions - in particular finance, accountancy and marketing, which tend to be more strongly entrenched in top management.....This present several problems. Most obviously, other groups are not going to step aside willingly and allow engineers to take a more prominent role in decision-making' (1986, p.118). but he recommends first that they be trained in 'marketing, economic and social considerations'. However, it is not the same as the view put forward by Jim Watson - that is, that the technology of the designer system makes redundant the need for such training and reinforces that it is the designer systems itself which allows designers to make appropriate decisions on investments.

return on investments or the lucrativeness of contracts. According to Jim, 'the current theory about the organization of manufacturing industry is that the various activities should revolve around the financial control and management activity.' That was, said Jim, the 'accepted wisdom' of manufacturing that Manufacture from Design would challenge. But Jim claimed that 'the heretical theory behind Manufacture from Design is that it is the activity of design which should be at the centre, with the financial activity to serve that central activity, not dominate and control it.' A view of manufacturing whereby the designer was 'restored to his true position', that is at the centre of the enterprise, was only possible with the techniques of AI research, according to Watson. Jim Watson called this a centrist view of manufacturing.

What Jim had mapped out was a scenario of various elements knitted together: the problems of evaluating contracts and new technology for their profitability, problems in flexibility of manufacture - the capacity to switch production lines quickly and, at the root of the problem, knowledge gain and loss. That last could only be solved, said Watson, by AI techniques ,which in this case was the Cally formalism for talking about design.

'Technical' Centralization

The centralization of designers within firms was mirrored by centralization in the 'technical'. RAPT code, the Functional Unit Module Taxonomy, and the balance of power between designers and accountants in making decisions were all the elements which Jim Watson linked together to enforce consistency on the creation and handling of knowledge. Most crucial to enforcing consistency meant not transforming knowledge out of the Cally formalism into another in order to accumulate the knowledge necessary to the eventual manufacture of the design. That, said Jim, would only recast the same problem of knowledge gain and loss. The implication of that was that Manufacture from Design was not in Cally's schema a 'decomposable' system. For designer system to be accepted as 'working', changes to the social world would be necessary. Ultimately it would be necessary for any company, said Jim, to either abandon its existing software or 'move to the field next door' in pursuit of the truly flexible and integrated manufacturing organization. The implication was to start afresh with the

Manufacture from Design system as envisaged by Cally. To ensure consistency of knowledge generated it had to stay in the Cally's formalism, according to Jim. Inconsistency in formalisms would go against the need for flexibility. It created, said Jim, more of the knowledge gain and loss.

The Cally formalism used to express knowledge throughout its generation was the solution to this problem and the answer to real flexibility in industry. It was a case of being more like Russian dolls than Chinese whispers.

Jim's argument had taken the route of a complete circle: in his scenario he had, in Latour's sense, brought the laboratory to bear on macroproblems. In so doing he was dissolving 'the inside/outside boundary', the boundary between the lab and 'society' (Latour, 1983, p.163). The problems of flexibility were to be understood as problems of knowledge handling which in turn were to be seen in terms of Cally's formalism. And in the hands of designers the knowledge made available by using Cally's formalism could operate like a balance sheet on which to assess the profitability of contracts or new investments and provide the consistency of information necessary to increase flexibility.

BEB management stated that they had an obligation 'to get something out of this project' in the time available. (That was interpreted by Cally's team manager as a product.) Crucially, BEB believed that they could not expect companies to give up the software they already had in order to take on a Manufacture from Design system en masse.

Reams, like BEB, would benefit from the eventual exploitation of a system which would reduce the time between design and manufacturing of a product by integrating the design function with planning, machining and assembly. The product which was to be the focus for the collaborators expertise was an electro-mechanical diesel injector pump produced by Reams. But the pump was not simply a focus or just one aspect of Reams attempt "to ensure total realism" in the project.

The product itself was key to Reams. The pump was a revolutionary design available in prototype and for which there were, according to Reams, "excellent market prospects." The Reams fuel injection company therefore saw itself as being a major focus for the project in its commitment to "introducing this fuel pump to the market as quickly as possible." The tight time-scales meant that the commercial considerations related to market needs for the new injector pump products might enforce a particular short-term course of action: 'a modular development of a highly competitive manufacturing system appeared to be compatible with the anticipated market growth of the fuel pump.' (Study Report). Reams also made it clear in the Study Report that they reserved the right to specify the order of priorities so as not to prejudice their market position. One particular short-term course of action would involve using currently available international hardware and software that would be "best for the job." That was said to be an important consideration in terms of leapfrogging experience gained in software development rather than starting from scratch in the effort to turn the prototype fuel pump into a marketable product. Another factor which Reams had to take into consideration was the major investments they had made in certain commercial hardware and software, CAD/CAM systems. The effort that had also been put into the training of staff in the use and maintenance of these systems meant in Reams view that it was "logical to try to interface with such elements rather than try to replace them with alternatives" (Study Report). That, claimed Jim Watson, was one of the reasons why Reams had not objected to using the modeller that would come from BEB's computer-aided engineering company. That modeller would interface with their existing investments in technology, their computer vision CAD systems. In other words, for the industrial collaborators there were constraints in terms of previous investments.

This constraint translated into the technical form of a modular system decomposable into its separable parts, not the integral, centralized one Cally dreamed of.

Cally rejected the idea that the designer system to go into a design office and be expected to work alongside existing software. For Cally, however, that might mean using hardware or software which would interfere with the goal of achieving a 'centrist' system. For BEB, however, the system had to be decomposable to fit in with 'our obligation to get products out.' The world was not as malleable. There was, said Alan Rogers, 'no other way' than to have a modular - decomposable - system.

Cally attributed BEB's attachment to modularity, as overinterpretation of the block diagram: that is that blocks should be seen as discrete packages. Something more profound was at stake, however. The modular and integrated approaches were connected to different views about the 'hardness' of the social world. From BEB's point of view this meant that the social world was not quite as malleable as Cally wished to portray it.

These were potential sources of conflict for the Cally team. The keenness to use the software and hardware that would get the pump onto the market or to use software or hardware that would get 'products' onto the market for BEB could be obstacles to Cally's goal of achieving a system that would maintain consistency of formalism throughout the product life cycle. In other words, it was Cally's aim not to be driven by software or hardware that might make it necessary to transform; to go from one formalism to another. As far as Cally was concerned the project was not about 'products' but proving the viability of the concept of integration - and integration as they defined it.

That meant centralized, uniform integration. That approach went wider at Cally than just the Designer system. It pervaded Peter's views on transport. I already knew from travelling with him how much he liked trains. But it was more than that. It was a consuming passion because railways embodied what Peter considered to be good technology. Train travel was a good and safe technology because it displayed principles of uniformity: a trained driver was devoted to the movement of passengers along rails especially designed and committed to trains. Trains were less likely than cars to lead to conflicting and sometimes harmful situations because they occupied space that was quite separate from pedestrians. Car travel was illogical. Cars created chaos because they represented an inconsistent mode of transport: individual vehicles driven by individual drivers with a variety of temperaments, travelling at different speeds was not a coherent form of transport. Indeed it was a situation that made cars 'dangerous weapons.' The car system represented an inconsistent and conflicting situation because unprotected pedestrians were often competing for the same road space as cars. Cars, people and public buildings were too close too each other. A chaotic situation ensued from this contradiction.

I found out - almost at considerable personal cost - just how far Peter was prepared to take his convictions: not being as quick to cross roads or as contemptuous of cars as he, I would find myself stuck in the middle of traffic as I tried to follow him across a busy road. He on the other hand would stroll out onto the road in defiance, making cars avoid him. This was not a side issue for Peter; indeed sometimes it occupied so central place in his thoughts that it annoyed the other researchers: 'He's spending more time writing his paper on a new form of transport than on the designer system.'

Because Peter refused to travel in cars he would sometimes leave meetings earlier than his team-mates in order to make his way to the railway station. Once he chose to eat alone in a bar while the rest of the team and Reams' designers and management sat outside for lunch to enjoy a rare hot day in September. But Peter found the cars near the pub oppressive, so the rest of us ended up going inside to join him and talk about the designer system.

Peter laid the poor state of the population's health and its inability to create wealth at the feet of transport policy. This was because of the inconsistency between transport policy and domestic policy. Cars were unhygenic in the sense that they were responsible for road accidents and deaths. That, according to Peter, reduced the capacity of the population to create wealth. So a better transport system was an approach to public health policy and that in turn was related to domestic policy. In Peter's views on transport even terrorist attacks were facilitated by the use of volatile fuel and the nearness of roads to public buildings. Public buildings and 'peopleways' were too close to cars and lorries. Here, again, was said to be an inconsistency between 'transport policy which encourages the use of machines burning such fuels, and the policy of HMG with respect to other explosive substances.' Uniformity and consistency were the name of the game.

Such an explanation would not of course be universally, or even widely accepted. Perhaps smoking, absenteeism, strikes, or international competition are more likely candidates for the state of the GNP. For many people, indeed most on the Cally team, cars were a convenience. Car rides could take them on a short cut to a central line station!

Similarly, Jim Watson's view of the way decisions were taken in companies did not go unchallenged. The overall project manager from the BEB team managing the project disagreed with Cally's 'simplified' view of the way decisions were taken in a company. He asked Jim Watson to remove reference to this from his paper for an important conference to be attended by industrialists and academics. What BEB objected to was that this was not a fair assessment of what went on in companies, it did not happen that way.

Ultimately this could perhaps be seen as a challenge to the centralization of Cally's formalism. but that issue of formal centralization was also tied to an immediate issue of social centralization: how the project should be organized.

<u>Organizing sites into a project</u>

A first very important task for management in the project was to organize the contributions of the individual sites into a project. One task of project management was to make the work of the individual collaborators visible and accountable not only to itself but to the hierarchy of committees that, at least in theory, controlled the Manufacture from Design project. They included the Steering Committee, which was one level above the Technical Committee in that it was composed of a member from each site who was not the site manager, perhaps head of department in the case of the universities and the director in the case of the industrial teams. Ultimately, of cause, the project was responsible to the Alvey Directorate. In the first few months of the project I was surprised at the amount of time we spent at meetings discussing the details of what were called the 'Terms of Reference' of the various committees that were responsible for the running of the project: who was entitled to make technical suggestions, when something should be overruled. Far removed from romantic flashes of inspiration in disorganized settings, technological work was inseparable from establishing the means whereby those managing the project could 'know' that technical work was indeed taking place on sites. In other words records would have to be generated that could be used to eventually convince the Steering Committee and Alvey that the group was making 'technological progress'.

The relationship between the project's Alvey monitor, the Steering Committee, Manufacture from Design's project management (itself a hierarchy of an overall project manager above the systems and software managers) and an individual site manager involved planning and collecting progress data (which was in turn broken down into man-hours of effort for activities completed in the previous three months, those planned for the next three months and the team members committed to such work). That way it was possible to have 'milestones' of work which could be monitored as either meeting or failing to meet targets. These categories would then form the basis of the progress reports for site managers, to be discussed at progress meetings with management, who then generated another round of reports for the overall project manager of 'Manufacture from Design' who in turn was responsible for what he called the 'synchronising' of site reports into a project progress report for the Steering Committee and eventually the Alvey directorate. That was the theory; to have the work of the individual collaborators eventually come together. But how? For what purpose?

To report progress collaborators would need something to be progressing towards. From the beginning it was made clear by project management that they would have to find a way of organizing the work both to meet the individual interests of collaborators (see chapter four) and to satisfy an overall project plan. And out of this common goal it was envisaged that the work of each site would have to form a chain of expected technological inputs and outputs. This chain was to be set in motion by managements production of 'activity network diagrams'. With a software package using an IBM PC to plan the activity networks, it was a case of technology monitoring technology.

The project was as a cluster of artefacts - these were the contributions of the various teams: design, planning, modelling, machining, assembly and maintenance - that were intended to come together to form a system. A system that was being referred to as a factory of the future. This is how management saw it; each should be able to work or make calculations for their own work on the basis of what others are going to do in the future (i.e not going along willy-nilly not knowing that what you are doing is of any use: 'We need to know we are being useful' said one participant) An individual site should be able to get on with its contribution to the system knowing that 'what was coming down' was what they expected to have.

All elements - design, machining, assembly - were going to be parts which mutually affected each other in a system but just how needed to be defined.

That was the theory. The practice was different. Collaborators would leave meetings saying, 'I still don't understand what we're supposed to be doing'. How those contributions were supposed to come together, who was expecting who to do what and how much were not known: 'What do we need to be able to do', 'What do we want from a planning system', 'What should the assembly cell be doing', 'when does maintenance come in'. For some it proved difficult to even think about a key aspect of the project, what it meant to represent design knowledge within a computer programming language: 'I can't visualise that task.'

In part this uncertainty was, according to some collaborators, because the project did not have a goal. As one researcher explained, work could only make progress if there was a goal: 'I see the project being run as a series of experiments, the results of which can be used or not. But you can't have an experiment without a goal or a concept towards which you can work.'

Jim Watson agreed that there was no goal coming from management. Since a plan of where they were going had not been worked out it was, in Jim Watson's view, the job of site managers to work it out between them.

As far as Jim could see, managements attempts to organize the project and collaborators was derived from how they saw the 'technical' contributions: as distinct packages. That was seen by Jim Watson to be the modular view which Cally said BEB had obtained of the project by misinterpreting the block diagram. The block diagram of the designer system was being reified, with the mistaken implication that all that had to be done to coordinate the project was to define the interfaces between separate blocks. But said, Watson, how could they do that when they did not know what was going into each box? Managements attempt to prepare spread sheets of 'technical' activity across sites was, claimed

Jim, a further indication that they were being expected to come up with a modular system and to develop products. Resisting a modular system in favour of a 'centrist' approach involved Cally in a process of placing itself at the centre of the project.

Microsocial Centralization

As far as Jim was concerned the diagram of a possible Manufacture from Design system was not truly representative of the place of the Cally's work - the designer system - in the overall project. In this diagram Cally was positioned on the far left, proceeded by the other contributions which were connected by arrows going from left to right. That, said Jim, represented a pass-oriented system; the knowledge from the designer system was portrayed as being passed through the different stages and that, according to Jim was what they were trying to get away from. Cally rather should be in the centre of activities with the other contributions around it.

But the project could only be centralized satisfactorily if those involved shared a common language for talking about the system. They were from a variety of backgrounds - engineering, computer science, psychology, physics and artificial intelligence - and from a variety of establishments - universities, big business, industrial research labs, and consultancies attached to universities. They needed to speak the same language and to know they understood each other. That as we saw in chapter 4 was one of the first requests from collaborators. But they should talk Cally's way. At some moments it seemed as if Cally was telling the others that they must not presume to understand texts, they must get texts from Cally and get them to explain what they mean. Jim Watson explained to me how it would be up to Cally to say that they had been understood, that the others were understanding[3].

Another attempt to enforce centralization was to try to limit the access of 'management' (as distinct from 'technical' people) to the meetings where the system was discussed. To do this Jim Watson tried to have Technical Committee meetings composed of what he called Participants and Observers; only participants could contribute to the discussion. Observers had to

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[3]A question of general sociological interest concerns the role of language in maintaining order. It would involve a longer period of participant observation to look at how Cally attempt to get others to talk their language for discussing the designer system and how in turn order is kept in a process of mutual sanctioning on the 'correct' use of language.

be called on to make suggestions. Under this arrangement management were invariably observers. Needless to say it did not find much sympathy amongst management.

Chapter Eight

The Man-Machine Interface in Rhetoric and Reality

Central to the rhetoric surrounding the establishment of the Alvey programme was the area of Man-Machine Interface (MMI), defined as the 'methods, media and mechanisms for enhancing cooperation between people and machines in an interactive environment' (Alvey Directorate, 1984, p.3). In this chapter I trace what happened as attempts were made to translate this rhetoric into the reality of project work. The Alvey programme generally laid much store by MMI for the success of the whole programme: 'MMI design quality is already a matter of concern to overseas manufacturers - witness IBM's policy of applying "usability plans" to its product development. UK manufacturers will need to take similar steps to maintain competitiveness, relying increasingly on the MMI R&D community in developing the necessary design capability' (ibid.). It was stated that unless some understanding of MMI was developed the full potential of present or future information systems would not be realised. Within the Alvey IKBS programme in particular MMI was thought to be crucial to the commercial success of a technology that was considered by many. The commercial success of IKBS - and of the Alvey programme as a whole - was said to depend on 'making sophisticated products truly acceptable to their users' (DOI, 1982, p.29). MMI was to be central to the Alvey programme. There were, for example, to be research centres to administer advice on MMI, and to make state-of-the-art research available to small firms that have no in-house MMI.

Systems had to fit with the humans who were to use them. One task, said the Report of the Alvey Committee, was to: 'Analyse human problem solving behaviour in complex tasks. Use this information ... to create systems which are compatible with human reasoning' (ibid., p.30).

By way of acting as a show-case for MMI, the proposed MMI strategy document stated that 'Particular emphasis is placed on the role of exemplar and demonstrator projects as a means of consolidating the technology and confirming its utility' (Alvey Directorate, 1984, p. 2). MMI was to occupy 'a special position in relation to the Alvey programme as a whole, where it has the essential role of representing the needs of the user in advanced IT projects.' And that relationship was said to be particularly strong in the area of the Large Scale Demonstrator projects.

To bring together the work of researchers, designers and users and link their work to the needs of industry was an important aspect of the MMI strategy. That was the Alvey line. However, MMI did not simply slide into the Manufacture from Design large scale demonstrator: its place on the project was to involve much negotiation and engineering amongst the various collaborators.

Man-Machine Interface and the Manufacture from Design project: Practice

The original Manufacture from Design proposal did not include an MMI collaborator, and in that shape was unacceptable to the Alvey directorate until an MMI group had been included. Eventually the Manufacture from Design project included as a collaborator such a group: the Human Factors and Technology Interface centre, HATI.

But that a 'slot' now existed for MMI was, some collaborators claimed, because it had been *made* for HATI. HATI's place, it was claimed, had arisen not out of any 'technological' need, as had that of the other collaborators, but because, as one participant put it, the director of HATI was a 'buddy' of Alvey's MMI director. The presence of MMI within the project provoked a variety of comments from the other collaborators: 'What is MMI?', 'It's just flavour of the month with Alvey', to 'MMI's got nothing to do with technology.'

So MMI and HATI entered the project as something of an afterthought. There was often a feeling of 'what to do with MMI?' on the project. Indeed management were often concerned that HATI was being left out of the project. Eric Cater of Reams came up with an idea to give MMI 'something to do'. He chose an engineering metaphor to describe the relationship of HATI to the other collaborators. It was a metaphor which made a distinction between who was actively contributing to the project and who was not. The other collaborators he said were the 'real cogs' in the project. MMI was like oil. It could help the project to go smoothly. MMI researchers could talk to the other collaborators about how they saw their roles in the project and how they saw each other.[1] But that was an essential role, and since Cater was an 'industrialist' (as manager for Reams), it is interesting to note that at this very early stage in the life of the Manufacture from Design project 'industry' did not see themselves as having MMI needs as the Alvey MMI strategy saw it.

Different groups were unsure of MMI's place in the project and were assigning different meanings to the role of HATI in it. No matter what the other collaborators might have thought about MMI or about its place in the project, however, MMI people did not doubt that they had a very important role to play. On yet another train journey - this time with a member of the HATI team - I was told how they were hoping to be involved on a creative basis not just on consultancy terms with the project. Frank Jackson of HATI spoke excitedly and was enthusiastic about MMI's role on the project, discussing lots of creative ideas that I did not follow like the possibilities of a system which would allow a designer to simulate his hands on the screen so as to allow manual positioning of mechanical components. And for an advanced information technology it was something of a surprise for me to

[1] Eric Cater was usually the one saying that the project was about 'getting on with each other' and MMI could be used in that way.

hear him say, 'I'm not convinced that there isn't still a place for pencil and paper in design, you know'. I sometimes wondered if the different people I met were on the 'same' project. In other words, 'interpretative flexibility' surrounded HATI's position as a collaborator on the project. But as we shall see, that same 'interpretative flexibility' did not surround only who was entitled to contribute to the design of the designer system, but also surrounded the nature of that design. At the opposite pole from HATI and MMI were Cally, and it is to their position that I now turn.

<u>Cally and representing design knowledge</u>

Three things were entwined in Cally's task: the *representation* of design knowledge, where design knowledge was *located* and how it was *obtained.* As we have already seen, the Functional Unit Module Taxonomy was Cally's formalism for representing design. And so an initial attempt at building a designer system began with codifying the knowledge needed to design a gearbox.

Encoding design knowledge meant in practice that Craig

Ward and Peter began 'loading up' the taxonomy from books and Craig's university notes. Craig copied articles from books showing the relationship between the types of gears as in a hierarchy. One popular book was an 1960s text on engineering design. Also to hand was Craig's knowledge of mechanical engineering as recent graduate. However, it could not be said that Craig had a great deal of design experience: when he attempted a design on our drawing board he had to have pointed out to him by another team member that his combination of components would not work.[2]

In what sense was the functional unit module taxonomy a representation of design knowledge? The taxonomy was a representation of design for the computer but Craig Ward pondered on how it was he was now thinking of design knowledge as a functional unit module taxonomy. The taxonomy was represented highly schematically in the diagram of the designer system, this was shown in figure 6. 2.

Craig reflected on how this shape influenced his way of

[2]Jim also claimed that Cally had practical experience of design: 'Peter is building his own concrete boat. He's a very practical guy. Certainly the oil on Peter's fingers were proof of a hard weekend's work. In other words it was not all theoretical.

seeing the design process as hierarchical. He wondered if he thought about design as a process which could be represented by a taxonomy within the machine because of its rectangular shape on paper. With the shorter sides at top and bottom his eyes progressed from the top downwards. Was it simply the way we looked at images, he asked me, that influenced his idea of the design process? Had the design knowledge been represented as a circle would that, he wondered, have changed the way he conceived of the design process and how it should be represented in the machine? As I was cast as the 'psychologist', he suggested it was something I might be able to comment on. Jim, however, told Craig not to read too much into his diagram. He had chosen the rectangle simply because it was a convenient shape for A4 graph paper and could eventually be turned into a clear overhead projector slide.

For Cally, representing functionality was fundamental to the designer system. Design, it was claimed, was a matter of satisfying the function that an engineering component was intended to have in the process of designing. Even buying Peter's wedding gift was a lesson in functionality. Going shopping on this occasion with Craig, Jim and Howard was an experience for me. As consumers they wanted a gift that was mechanical. So they chose an old fashioned coffee-grinder. Howard thought I was some sort of philistine. When they suggested coffee-grinder, I immediately came up with electric. No, my shopping companions told me, mechanical was much more interesting for someone like Peter. When the shop-keeper asked us if we wanted it 'made up' or 'as it is', I immediately said 'made up'. But I was soon put right. Peter, they said, would enjoy thinking in terms of spatial relations and how the parts should go together to function. Peter obviously appreciated his present: he wrote his thank you note to us in Prolog clauses to express the functionality of the grinder's related components: input beans, turn crank, output ground coffee; 'Yum, yum'.

<u>HATI and the designer system</u>

HATI, by comparison, did not begin with functionality, but with systems: systems composed of machines and humans. HATI's view of developing technology meant paying attention to what they called the social and the technological 'sub-systems' that composed 'production systems'. The design of a system was both organizational and cognitive. 'The normal procedure of designing systems does not make explicit mention of the socio-technical elements. What tends to happen is that the technical systems are defined first and a social system is put together afterwards to try to cope with the technical system' (HATI document). This sort of approach had, according to HATI, led to disasters like Three Mile Island. That technological failure happened in part because the control room had been inappropriately designed for the human operators. So it was, in HATI's view, important to adopt an approach that involved human factors in the design of the technology to avoid other 'sub-optimal' (failure) situations like low productivity, job dissatisfaction, reduction of efficiency and high labour turnover.

Translated into the context of the Manufacture from Design project, this HATI perspective implied finding out how designers thought before designing a system to assist them. This might have seemed as innocuous conclusion, but it was to spark fierce opposition from Cally.

Who constructs a knowledge base?

After one meeting with HATI's site manager Peter said what he did not like was groups like HATI coming along with 'fixed ideas' for the project; this, he said, was the way with MMI. Early on in the life of the project Jim wrote to BEB management for the project to point out that HATI's concern with 'how designers think' was 'going over the top.'

HATI's 'fixed idea' was to see as problematic the representation of the design process as a functional taxonomy on the grounds that it might not in fact adequately represent the design process. Perhaps designers did not *think* in terms of a taxonomy. More explicitly they suggested that Cally's basic assumption might be wrong. It might not be the case that the designer designed according to functionality. It might be that designers designed according to shape. The designer might *think* according to shape or not *think* in terms of a taxonomy.

This meant, for the MMI team at HATI, that they should have input to the heart of the designer system, into how knowledge was represented - at least in the sense of wishing to have it recognised that the knowledge base was still a flexible issue and that MMI had some input to it.

As far as Cally was concerned the MMI influence had to be 'on top of' the designer system, not at its heart. Design *was* a functional process. Crigbank drew the analogy with air travel: 'MMI is important, but it is not more important than understanding the basic aerodynamics. You have to design wings, control surfaces and an engine to provide the necessary energy. You define components to perform function and then you start worrying about how it is a person comes to control those components. So with the designer system, we don't progress by designing cockpit. We progress by designing for function. If we don't know anything about physics or aerodynamics and design for a human requirement we end up with Doctor Who's Teleportation machine - you dial Washington and you materialise in Washington. That's an aeroplane or a device conceived of for performing the function of transport without any reference to the physical principles whereby transport can be accomplished. So if you are doing a Designer System you have got to think what the basic engines are, the basic structure to support design and then you think how to present to the human.'

An MMI-led project would not work according to Crigbank. If you are "dominated by MMI you end up with Doctor Who's Tardis and not an aeroplane. Some people might argue that the plane analogy is not a fair one because they'll say that design is a more cognitive activity than flying. I would say that AI is about the automation of cognitive capabilities and MMI is not. It is about matching the human to the machine. MMI is concerned with the capacity of people and how that can be matched to the capacity of machines. In the designer system that has to do with things like what the memory is like since you don't want to force the human to remember too much and how good they are at typing. And how good they are at looking and seeing things on the screen. So you want to bring things together. You make sure the plane has wings and then you start worrying about MMI."

What made the designer system powerful as a design tool, according to Cally, was that it was based on the language of mathematics. Mathematics was, Peter claimed, unambiguous, therefore the consistency that they claimed as being important to flexibility was also taken care of by the Functional Unit Module Taxonomy's mathematical representation. The system would have to represent what was implicitly understood by designers and it would have to make this explicit for the system to work. But it would be not a bad thing, said Jim Watson, for designers to be more rigorous. And most importantly *designers would adapt* to the designer system. It was the view of Cally's colleagues within the AI department also, that 'designers might not like it at first but they'll get used to it when they start seeing results.' Or, as Craig Ward put it, 'You can get a left-handed pygymy to drive a left-handed Russian tank.'

In the case of the designer system, HATIs socio-technical approach suggested that it would be 'important to understand the psychological aspects of the user in order to construct the knowledge base, the representation of that knowledge' (HATI document). HATI's statement expressed their interest in 'expertise gleaning' since what they wanted to avoid was what they called a case of Rambo in Wonderland; the designer being hit with information that bounced off him like bullets. This, they claimed, was what would happen if a MMI was treated, as Cally wanted, as an interface to built on to the system once the AI researchers had designed it. MMI should not be used just to try to make the designer system palatable to the user, if the way a designer 'actually' designed was not represented in the knowledge base.

Cally, however, saw themselves as designing a methodology for taxonomy building which, according to Craig Ward, would *eliminate* the need for a knowledge engineer task, for 'expertise gleaning'. The methodology would enable designers to encode the necessary knowledge straight into the designer system. He showed me an article about the knowledge engineering 'problem': how it could lead to information being misinterpreted in the process of gathering it. Cally were therefore addressing and solving an important problem by getting the designer to encode the knowledge himself, according to set guidelines, and eliminating the need for a separate knowledge engineering function.

This difference of approach between HATI and Cally is perhaps of more general significance. Diana Forsythe is an anthropologist who has studied in an AI laboratory and looked at the ways in which AI workers perceive knowledge and how it should be gathered. She undertook her study (1987) as a result of being struck by the ways in which two sets of workers, social scientists and AI researchers, both concerned with the gathering of and interpretation of knowledge, nevertheless took very different approaches to the task of knowledge gathering. The social scientist considers the gathering of knowledge to be problematic, requiring careful methods to obtain; extended periods of observation or interviews which are prepared in advance. The style of the interview is carefully considered and there are plenty of methodological texts to advise on matters such as the benefits and disadvantages of structured or non-structured interviews to suit the interviewee in question. By comparison, the AI worker, she claims, does not see knowledge gathering to be problematic. Because knowledge is thought of within AI as residing in heads or in books it can be 'extracted'. Humans are only a problem to the extent that they get in the way of more efficient means of gathering knowledge. Getting the 'human out of the loop' in knowledge gathering is, she claims, a goal of AI workers. AI Workers, she claims, only see themselves as making do with talking to experts (without consulting texts on interviewing, considering it to be a matter of commonsense to talk to an expert) until they can develop techniques to gather knowledge automatically.

MMI and the 'delocalisation' of the designer system

Jim Watson described the building of the designer system at Cally as experimentation between Peter and the machine. Representing functionality was, said Jim, worked out everyday between Peter and his workstation. Peter's creativity was held to be responsible for the designer system. "That's what he is doing all the time, working out". Finding out how designers *think* when they design was not an issue. Why not? Because said Jim designers did not know how they thought.

HATI's approach, according to Jim Watson, was all 'psychology' and 'opinions'. Jim greeted HATI's request for a colour workstation with some scepticism: 'They *perceive* they need colour, they don't *know* they need it.' HATI's work was all ideas, and it was not situated in a body of practice. HATI, said Jim, did not always reference their work therefore you had to think it was based on opinions. That was the difference, said Jim, that Cally's system was based on the fundamental and unambiguous nature of mathematics. Jim disliked what he saw as the ambiguity of the

English language: words like tale and tail. The language of mathematics was preferable because of what he saw as its indomitable and unambiguous nature. The designer system should therefore be based on the fundamentals of mathematics in order to ensure that knowledge was consistent. It was essential to making implicit knowledge explicit. Implicit knowledge was what designers worked with; implicit knowledge was not always communicated. Again it could lead to the sort of misinterpretations which lead to Naval Brass type situations, described in chapter seven.[3] It was that, claimed Watson, which would give the designer system its universality.[4]

Jim Watson's view was that since MMI was concerned with how designers think then a system led by MMI principles would be 'a disaster'. Implicitly, he was disagreeing with the centrality awarded MMI by the Alvey programme. The designer system, he

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[3]I found it amusing that language was not treated in quite the same way when it came to issues of gender like the use of male pronouns. Then it was a case of not changing the language but our perception of it. That is think about men and women when the male form is used. The language could be left as it was if we *thought* about two genders.

[4]He is not alone in ascribing to mathematics a trancendental nature. However, see Bloors's 'Polyhedra and the Abominations of Leviticus' (, 1978) and Lakatos's(, 1976) study of the history of Euler's theorem. These show that mathematics, which confronts us the most objective of discipline,s can also be studied from a sociological perspective.

claimed, would not spread if it was based on MMI. Jim envisaged expanding the circle of users. This he described in terms of expanding concentric circles, moving out from the lab and the users/researchers at Cally: "It would go out from here to more and more users." The more it reached, the greater the proof of the system's generality; that they had in other words designed 'the designer system'. Designers, he claimed, would *adapt* to the designer system since it was based on mathematics.

But, according to Jim Watson, MMI could, if given a place in the construction of the knowledge representation affect the ability of the system to spread: 'I'd be worried about the designer system depending on MMI for it to work.' Why? It would, said Jim, limit the system's use to those designers who happened to think in the way that MMI had worked it out for. As far as Jim was concerned, then, the subject of MMI was *itself* as idiosyncratic as gold-plating, equivalent to the experiment that worked because it was 3am or because it happened at Warwick university under the direction of Professor Jones (MacKenzie, 1987). What Jim would have liked was a designer system that was as successful as the pocket calculator: "What's so great about the calculator is that it works independently of how it looks or how it is presented to the user. It works because the technological principles have been worked out." What Jim Watson then suggested was that it might be a good test of the system if it can work with any MMI. 'Any MMI on top' was equivalent to using different ways of interacting with the machine for the design task. That it should work with any MMI was the equivalent to saying that an experiment can only be considered to work, to produce facts, if it can work at any time of the day, in Rio de Janeiro or Clacton-on-sea, and does not depend on the skills of one scientist to conduct it. This was a suggestion for how to make HATI 'useful' within the project: to get them to test whether the failure of the system to increase its concentric circles is the result of poor MMI or the fundamental nature of the system.[5] A Designer System could not be accepted as working if it was 'MMI-led' since MMI was, in Jim's view, by its very nature an idiosyncratic and hence a local achievement. Like the experiment which remains a private discovery, the Designer System would not leave Cally's laboratory or at least get beyond

[5]What would obviously be of interest here would be the way in which a test as Jim Watson proposed might be set up to evaluate the designer system. How it would be determined that the problems associated with using the system lay with the taxonomy or the MMI. In other words there is always the possiblity that interpretative flexibility would surround the results of such a test.

the particular idyiosyncracies of a few designers.

At meetings, HATI wanted to establish the reversibility of the Functional Unit Module Taxonomy as a way of representing design knowledge and to contest the idea that MMI was an afterthought for system designers. HATI stated, 'As long as you don't think you are coming so far and we are going to build on top. At the meeting Jim Watson seemed to deny that this was Cally's scheme: 'Oh no ... like you would have to take what we give you.' But away from the meeting and on our way home Jim Watson told me that the FUMT was fundamental. That was not brought into the public arena.

This was not uncommon. Often different points of view were not brought into public confrontation. An observer of meetings only, or other such formal settings, would thus gain only a partial picture of the social shaping of technology. Therefore it is necessary to follow scientists and technologists around to appreciate that agreement might be context dependent. As we follow them away from meetings we can see the different strategies that technologists use to maintain their own position.

'I'm keen to have some independence from MMI', said Jim Watson. An initial attempt was to tackle this at the level of the technical committee meetings by dividing participation in meetings between 'participants' and 'observers'. Participants actively took part in the discussions of which they were considered to be centrally involved. Observers were collaborators who could be present but who would be expected to sit on the side lines, who would be asked by a participant to offer an opinion. Invariably, HATI was an 'observer' - a situation with which management, attuned to MMI's centrality to Alvey, was uncomfortable.

Within the Cally team HATI were referred to as 'a bunch of furniture removers.' It was a deliberately derogatory term which was intended to get a good laugh at talks within the department and was used to refer to what Cally thought should be the concern of HATI within the project. It referred to MMI work in the 'narrow' sense of ergonomics as defined in terms of the comfortable chairs on which a designer should sit, the resolution of screens and what sort of computer they might use. That should be HATI's concern.

For Jim Watson the place of HATI was 'off our backs.' To that end a team meeting was called. And so Crigbank came up with a 'technological' response to HATI, an MMI for the designer system which he called 'table-topping.' I asked Peter why he was doing this? - so 'HATI can fuck-off' he replied. I asked Craig, who had been at the meeting, to explain it to me but he did not understand it: 'Peter has some good ideas but I don't always follow what he's on about.'[6] But Peter did develop a pictorial representation of the designer system which would make it easier to use the taxonomy. It was a pictorial representation of the taxonomy; when you clicked with a 'mouse' a box labelled with the name of a module the relevant information about that module was available to the designer.

A participant observer?

The different approaches were not confined to just HATI and Cally. The subject of MMI raised concern from a variety of collaborators. Reg Scott, site manager of BEB Machines, announced to a meeting he held with Cally that HATI were

[6]As it transpired table-topping was not used.

attempting a take-over-bid. Scott took the view that MMI was about 'marketing the system, making it look good.' When I asked him what he meant he replied 'why do you always ask me?' When I tried to explain that he was the one that always spoke about HATI, he said 'you're always defending them'. I, after all, was a sociologist. What was the connection: 'They are doing stuff on *socio*-technical systems and you're a socio person. You're like them. I bet you're a spy working for them. You're always talking to them. You're always nodding when they say something. The socio has nothing to do with technology. It comes in after you've designed the technology.' As a good relativist I did not nod my head! But what was interesting is that he saw me in this light: my 'questions' were taken as a defence of HATI. And any attempts I made to 'protest my innocence' were only taken as further defending HATI. (Was I to join in some of the fun poked at HATI?) Sometimes it made me uncomfortable, because he would say he had seen talking to 'them' yet again. He would sometimes even wink at me across the room as if to say, 'caught you!'. If I was a native member then I was being seen as a member of the 'wrong' side and that made me feel nervous.[7] It probably was not all in

[7]There was almost something macho in Reg Scott's views towards MMI. He told me stories about the back streets in Birmingham where engineers kept lathes in their

Reg Scott's 'head' however. HATI's Clive Mint did seem to see me as some sort of ally in his struggle to get recognised. After meetings he would sometimes ask me 'what did you think of that then' and he would say he couldn't wait to see what I was going to write about 'all these guys' in the sense of some sort of exposé of the truth.

A particular question Mint asked me was how had I gone about learning the language of AI? The HATI team had to do this in order to influence the Cally team: 'we have to understand the way they talk in order to convince them of the credibility of what we have to say before its too late', Clive Mint explained to me.[8] He seemed to see there being a point at which it would be 'too late' to change the system. Although he didn't specify when that would be or what that time would 'look' like, there was a recognition that the system was not infinitely malleable. Why it was not too late yet, why they felt they could still make an impact was not spelt out, however. An interesting general issue

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back gardens and where they did cheap but good engineering jobs, repair work and the like. The way he spoke of it was to conjure up images of rolled-up sleeves and hard graft.

[8]For Craig Ward, it was HATI's lack of programming experience which excluded them from making a serious contribution: 'how can they make pratical suggestions. The don't write code, they can't know if what they suggest is implementable. If someone had programming experience you might say "well okay"'.

lurks here: at what point the technology becomes immovable for those involved? As I have said, for Clive Mint of HATI it was important to understand the language of Artificial Intelligence as used at Cally in order to make some impact and get accepted by Cally as making an impact. But that was not as clear a task as it sounds. As Jim so frequently said to me 'It will be up to us to say whether they understand the way we talk here.'[9]

Part of HATI seeing me as an ally was Clive Mint's remark to me that Craig Ward was sounding just like Jim Watson. Clive wanted to know if he was always like that. Since within the group at Cally there was not a coherent point of view as regards MMI, I felt I could have said that within the team there was not always unity on MMI issues: some members did feel that MMI did have a part to play in how the system was designed.[10] I found this an awkward situation to be in. There was the methodological

[9]There is an interesting comparison to be made here with the work by Ashmore, Pinch and Mulkay (, 1987) on how health economists attempt to get medical doctors to apply to their practice of medicine the principles of economics. The authors are interested in the way that the health economists 'translate' (Latour, 1983) medical practice. In the case of the MMI workers we can see that they to wished to be able to influence Cally but they needed to learn their language and they also took the position that there was a point beyond which translation would be impossible.

[10]MMI, said Jacobs, did influence what you did to the knowledge base. They should listen to what designers want.

problem of maintaining some neutrality. There was a loyalty I felt towards Cally and the fact that perhaps on some occasions they wanted to present a united front. I evaded his question.

Artificial Intelligence, designers and the designer system

HATI was not alone in its concern over the construction of the designer system. Reams, the end-user, was also concerned. How 'real', Reams site manager Eric Cater wondered, was a system that was encoding the knowledge of engineering from text books and not from brains. Where was 'real' knowledge located? Eric would remark: 'We want brains in there (pointing to a computer) with a curly wig around it.' The system was intended to use the knowledge of the Reams designers, and in particular their knowledge about pump design in order to demonstrate the validity of the system, 'to the watching world.' The validity was to be demonstrated by the use of a 'real' product, the knowledge of 'real' designers and in a 'real' factory.

Reams was a company in transition. What was evident was the move from older designers to younger, multi-skilled workers. There was quite visibly two groups of older and of younger workers. On arriving Eric Cater introduced us to Michael Gray, designer at Reams and a key figure in the design of Reams' 'revolutionary' fuel injection pump. Michael was about to retire and what Eric Cater wanted was, he said, 'to get Michael's brain in the designer system'. Otherwise he was going to leave the company taking with him all the knowledge and experience he had gained over the years of working for the company and on the design of the fuel pump. Eric's goal was to get that in a form that could be used by the new breed of engineers; 'lesser skilled' engineers, he called them. This was considered to be a pressing need. People learned things and took it away with them because they never wrote it down. Therefore, according to Cater, the designer system should be a way of retaining knowledge.

The Cally team had come down at Cater's request to talk to designers and find out how they designed. I had overhead him tell another site manager that Peter was "still not concerned with the way designers think." Here in the Reams factory, Cater felt Cally would get to talk to 'real' designers and find out how it was they did things. After talking to the designers, Watson felt that they used something akin to a taxonomy. However, designers were not totally convinced by the system, as they explained to Howard and

Craig. Why was it, they asked, if the system was not intending to replace skilled engineers was it making knowledge explicit in the form of prompts - knowledge that a skilled designer would not need to have represented explicitly? And that very question caught Howard off balance. About this question Howard told me: "That was a good question. I hadn't thought about that before. I think I said something about the designer system holding the information that was in text books." [11]

It was part of Eric Cater's job to sell the designer system within his company and to do that successfully he had to convince management and designers that the designer system was relevant. The rationale for a designer system was clear to Eric Cater: "we need a designer system for the same reasons that British Leyland had to rationalise: the economic climate dictates. It takes years to train designers. That's a large financial investment and if we can use cheaper designers, that's designers who don't require the same amount of training then so much the better." Since part of

[11] When Clive Mint saw Howard Jacobs talking to designers he asked Craig Ward: 'Is he trained?' Craig replied ,'Its just commonsense'. D. Forsythe (1987) notes something similar, which is that AI workers do not see the need for any special methodology: that knowledge gathering is just about talking and knowledge can be transferred by talking.

Ream's organizational experiment (see Chapter 9) was to rotate engineers, doing jobs they did not always have a great deal of experience in, the system would have to have a way of retaining knowledge and passing that knowledge on. To be relevant it should represent the way designers think. According to Cater, ninety percent of design knowledge came from experience and history: what you were trained to do and what you found out by having done it for so long. It did not come from books, which was where Cater claimed Cally were getting most of their knowledge from.

Cater was still concerned that Crigbank was not looking at how designers were thinking: "Dare I say it", Cater asked the Cally team, "I know its heresy, but designers do think in graphical form, maybe they do design in terms of shape." In Cater's view the taxonomy itself had a structure which might not represent what went on inside the heads of designers; the structure of the taxonomy did not represent associative memory. The taxonomy required that those modules further down the tree inherit the characteristics of their parent, that is the module above. It did not allow null inheritance or multiple inheritance of functions. In a debate that took us to discuss in a more light-hearted vein whether a three-legged Indian elephant was indeed a child module of the parent elephant, Peter replied that non-inheritance was not possible. A module must inherit all characteristics for it to work "and that's it."[12]

That *was* just it as far as Eric Cater was concerned: Peter's concern was getting the FUMT to work. According to Cater, "Peter had a technique before he had the problem. He's looked for a problem to test it out." But he was not, said Cater, addressing the problem of how it was designers happened to think and on the basis of that design a system able to retain knowledge. Although Eric Cater was impressed by Peter's interface to the designer system - the graphical display which when clicked

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[12]Within the Cally team itself there was some concern that inheriting a single function, not allowing null inheritance or multiple inheritance was 'Because Jim says so. It's dogma really.' Slater's work was the basis for the designer system and the success of Slater's program taken as setting a precedent for extending module hiearchies into mechanical engineering. 'We know that FUMT works', Jim Watson was to say to any who doubted the taxonomy. But for researchers like Craig Ward using Slater's work was, in his opinion, easier said than done. To arrange according to functionality was not obvious: 'what functionality?' for there was more than one function according to which bearings could be arranged. And if the function of shafts was to rotate then Craig could think of an instance, a spindle shaft, for example, which did not rotate. At one point Jim Watson even suggested they might benefit from talking to a zoologist to find out about classify knowledge. Perhaps Harry Collins would suggest that the difficulty the team experience in creating the taxonomy is simply the problems that are encountered when AI workers attempt to encode tacit skills.

would give design information - he was not sure that the Functional Unit Module Taxonomy was the best representation for the system.

Cally, it is worth noting, did not share Cater's social agenda of making it possible to use less skilled designers. They insisted: 'This is a system for use by expert designers.' 'We are not in this to see the demise of human designers. The system will not be of use to novices.' The system, according to Jim, was more than about retaining knowledge: it was a mathematically consistent way of representing design.[13]

Finding Cally's position inadequate to their perceived needs, Reams recruited HATI. To find out how designers went about designing, Reams decided to invite the HATI team by getting them down to the business park to watch and ask questions of and watch designers for six weeks. The move was not well received by Jim Watson: "MMI should go on top or else I'd be worried about what we were doing here." He objected that HATI would not know which "technical" questions to ask the designers or how to

[13]It was Cally's concern however to explore the building of a general designer system, not one specific to fuel pump design. In chapter 9, I will explore further the problems the project as a whole faced in defining and demonstrating a convincing demonstration of a factory of the future.

interpret their answers. It was, said Jim, the technical people at Cally who were capable of asking designers questions. The implication was that design is about the equations designers use. Ream's Eric Cater was, however, not particularly concerned about this proposed 'incapacity' in HATI. He wanted them to watch designers, talk to them about what influenced their decision when they thought, and to see when and where they thought about shape. As it turned out that designers at Reams had not been dismissive of HATI. Indeed they had greatly enjoyed their visit - they thought Clive very sociable and 'a great laugh'.

Reams was not alone in wishing to involve MMI on the project. At the same time BEB was submitting to the Alvey directorate a proposal for an enabling technology on MMI. Along with British Aerospace and HATI, BEB had put together a proposal, eventually accepted, for MMI in computer aided design technology. Around this time Jim Watson was to change his approach to MMI and its relation to the designer system. It was no longer the case that MMI should be a test of the system's universality. Rather, what he now felt was needed was an MMI to bring out the full potential of the designer system, an MMI linked closely to the work at Cally. However it was an MMI to be driven by the 'power of the designer system'. In this changed approach, which gave importance to MMI as a way of getting to the 'full potential of the taxonomy', the direction of influence was still to come from Cally.

More heterogeneous engineering was on the cards, however. In a phone call to me Jim Watson spoke about HATI's attempt to form a design team to broaden design responsibility beyond Cally: 'HATI are feeling left out but I want to resist the formation of a design team. Things should be driven by need, and it is up to us to determine that need.' The task that faced Cally was not just to convince others that groups in general, and a design group in particular, should be driven by need. Rather that task required an extra bit of heterogeneous engineering and that was to convince the other collaborators that it was the Cally team *itself* which should determine need.

These manoeuvres might seem to be of local significance only. But ultimately they represented attempts to define the relationship between two different technologies, MMI and IKBS.

How the relationship between MMI and IKBS has been worked out subsequently is beyond the scope of this study. One thing, however, is amply clear: that the dictum of a policy-making body such as the Alvey Committee Directorate was not sufficient to determine the place of MMI in reality rather than rhetoric.

Chapter Nine

Constructing Success

Obviously, it was important for those involved that the project be a success. But what 'success' meant differed radically from group to group and context to context. In this chapter, I review some of these different meanings of success, and how the participants sought to achieve it. I begin with the most ambitious version of what success meant - that the project would lead to a demonstrating the possibility of a significant, maybe revolutionary, change, both organizational and technological, in factories. As the chapter proceeds, however, we shall also find more modest versions of what it was to succeed, versions which nonetheless occupying a great deal of the time and effort of participants.

A 'grandiose' version of demonstrating success.

The site for the final demonstration was to be a new plant set up for the Demonstrator project by the Reams company. Most importantly this site was to be the location for an organizational experiment in small-batch engineering. The aim of the experiment was 'to determine whether professional engineers can satisfactorily operate a plant without specialisation, demarcation or supervision' (Reams document). The 'experimental steps' were - no hierarchical structure, introducing group working rota including weekends, automation of unrewarding jobs or the use of sub-contract labour - what Eric Cater like to call 'Rent-a-Yob'.[1] Sub-contract work had 'advantages' according to Eric, 'Even if we tell a sub-contractor we're happy with their work and we'll use them forever they know that you can still turn round and dispense with their services.' In addition, the experiment called for a wide range of training, wide range of skills and experience, no personnel function, self-supervision and team building exercises and importantly no union recognition.[2] The organizational approach meant changes to the

[1]Eric Cater liked the deferential and the cultured worker. The Germans were appealing because even the 'ordinary' worker took an interest in music and politics, unlike their British equivalent. He also enjoyed a visit to the Burrell collection because the museum servitors were polite and opened doors for him and his family.

[2]Deen's site manager literally had his tongue in his cheek when he suggested to a technical committee meeting that unions should be consulted to discuss the design of the system: 'we should have union people here to ask them what they think of what we're doing.' He knew he was saying something contentious. The remark was talked over as if it hadn't been said and participant's addressed themselves to the next item on the agenda. This tends to support the criticism that Russell (, 1986) makes of Pinch and Bijker's (1984) Social Contruction of Technology approach (SCOT) and their Relevant Social Groups. Russell objects to the SCOT approach because it treats

workforce: no operators, setters, works engineers, foremen or personnel, minimal machine manning and paperwork. And finally all employees were to be staff and skilled and the plant to be in operation 7 days, 24 hours a day. These were to be flexible (rotate jobs) and skilled, graduate level engineers whose qualifications it was believed would motivate them to loyalty to the company. That, said Eric Cater, was in contrast to the bored minder of some machine who, he claimed, was 'like a time-bomb waiting to go off.' Although particular details about the Reams experiment were not released within the project Eric Cater explained how Reams were attempting to undertake a new type of organization along the lines of General Electric's experiment in self-management: teams/group work, rotating jobs, incentive schemes. Eric also told me that 'The Bible on how to make large organisations work' was the book 'In Search of Excellence' by Peters and Waterman. He was impressed to read about the

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as relevant to the production of technological knowledge only those groups actively involved, in other words those who have access to the site of the production of knowledge and ignores those who may be actively excluded. However, the inclusion of other groups might not increase the range of 'interpretative flexibility' surrounding a technology in any way that subverts the likely route to 'closure'. Marxist approaches within the sociology of work have suggested that getting workers onto directors' boards as part of industrial democracy schemes does not lead to their participation in the decision-making process in any way that upsets the current agenda. Rather, they find their 'interests' repressed by the profit constraint (See MacFarlane, 1981).

success of companies like MacDonalds which had managed to secure commitment from workers by getting them to wear caps when they served up 'burgers, 'put a white coat on a worker and they think they belong.'

There were more tangible signs that the Reams factory was an experiment. The place seemed impermanent in appearance and the kind of port-a-cabin office smelt new like it had just come out of a plastic bag. Situated on a Business Park, it was accessible only to 'authorised personnel.' Like an experimental control variable it was intended to be kept 'secret' in order to avoid, as one engineer put it, 'an adverse reaction' from other sites and in particular from the unions. When I went with the Cally team to visit the site, our taxi-driver had some difficulty in finding it! At this time the machine-tools were being installed. The shop-floor was clean and tidy and the machines shiny-new. Only the odd bit of swarf gave the slightest hint of activity. It was also extremely quiet apart from a demonstration we were given of fuel injection. The Reams experiment, however, was intended to act as 'catalyst' to spread to other parts of Reams sites. On seeing a rotating globe on a Cally workstation one of Reams engineer/managers exclaimed: 'That's where we're aiming at: the world'. And they were going to get there, they wrote boldly across a whiteboard by 'Ruling the World with Artificial Intelligence'.[3]

The organizational changes desired by Reams required what they called 'Methods of Achievement'. This included the intention to use minimal manned machines, to train staff in all production engineering, machine maintenance, electronics and computing, to link computer aided design and computer aided manufacturing (linking production control computer and the NC machine tools), and maximise integration by computerizing tasks. In other words, the Reams experiment made it clear that it was not technology which would lead to, or require changes in, work-roles in the sense of technological determinism. Rather the desired 'effects' of the organizational experiment were to be taken into consideration in the construction of the technology itself.

The Reams Experiment: A neo-Fordist model of the future factory

This relationship between the organization and the technology changes draws noticeable parallels with much current

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[3] I was told this by one young Reams' engineer sponsored to do a PhD at Cally working on the Cally designer system.

writing on the the production process. The Reams factory was a neo-Fordist model. This writing has focussed on the changes from Fordist principles to neo-Fordist ones (Aglietta, 1979; Blackburn, Coombs, et al., 1985). Capital accumulation based on Fordism is claimed to be in crisis. The Fordist techniques of mass production technology, dedicated machinery such as assembly lines and the organization of the workforce cannot be extended into small-batch engineering. But it is changes to small-batch engineering which are said to be important for an economic upswing. Blackburn *et al* explain that small-batch engineering is important because of its position in the production of capital goods: 'transformations in technology and organisation in this sector which result in cheapening its products are likely to have widespread effects throughout many other sectors which use these capital goods' (Blackburn, et al., 1985, p.108). Neo-Fordist technological elements include control mechanization, flexible production of a bigger range of products, the integration of design, production and distribution. And planning stages in advance as a total system and so subjecting them to scientific and mathematical representation.

Within the Reams experimental plant there was a vision of the future: a plastic model! However, demonstrating the Manufacture from Design project on this site was for some time in the future and goes beyond the time of my fieldwork. The demonstrator projects, as I have already discussed in this thesis were an important part of the Alvey programme's social engineering. They were intended to be precursors to market products, with industry playing a vital role in their shaping. They were also to be instrumental in rendering IKBS available for decision-making by senior management in industry. Reams was the user company where the 'realism' of the project was to be demonstrated. This early phase in the life of one demonstrator however shows that there were competing versions of 'reality', confusions about what could be achieved, and different versions of success. These all involved heterogeneous engineering, but mostly of a much more mundane kind than in Ream's new-Fordist factory.

A 'mundane' version of a demonstration: constructing a demo

Bringing the work of the Cally researchers together for the first demonstration of their software involved the sort of preparations usually associated with the staging of a theatrical production. Indeed, Cally used similar techniques: selection and preparation to the best of effects. They arranged what they called 'dress rehearsals' in front of selected members of the AI department who in turn saw themselves as role-playing the part of the other collaborators. Cally's MMI was deliberately called System Design Interface so that HATI would not think 'we are stepping on their toes' and trying to displace them from the designer system. 'Honest bugs' were removed and parts of the demonstration were saved as images, said Howard Jacobs, so that the system did not look too slow. What should go into the system was prepared in advance: values were put into equations which in turn were worked out longhand on the whiteboard. The 'correctness' of the designer system was checked against the longhand versions. At the advice of the role-playing audience Cally wrote what they called 'scripts' to guide the viewers through what was appearing on the screen. There were separate scripts for the demonstrators themselves, with prompts to remind them what to say at certain stages of the demonstration. And according to programmer Craig Ward these were sometimes reminders to 'talk over' particularly creaky points in the demonstration to divert the viewers attention. There were also times designated for the audience to ask questions which was not during but before and after a demonstration. Last but not least time was spent, as in all 'performances', on the backstage work of making sure the screen was visible by playing around with lights in the demo room and altering the font size. Even the chairs were arranged to make viewing comfortable.[4]

When it came to demonstrating, however, not all the audiences were as attentive as some of the collaborators; 'too clever by three-quarters' was what Craig Ward called one site manager who spotted a Cally error. For it was a demonstration at Cally attended by Alvey's MMI director and the director of the Large Scale Demonstrator projects that had to be the most bizzare I had witnessed. One director fell asleep almost as soon as the demonstration began and the other, suffering from back-ache, lay on the floor lifting his head only occasionally to catch a glimpse of the screen. How could Cally be said to be

[4]Researchers did not share knowledge of the system's various parts. Its production was fragmented and designated to different workers. This was usually evident at demonstrations. Once the phone interrupted one researcher's demonstration. As he left to take the call, the audience expected another researcher to take over, but the latter replied, 'I don't know anything about this.' I was told that if I wanted to understand the RAPT work on the system I should go to the other demonstration (the same demonstrations were run simultaneously in different rooms) where the researcher with RAPT knowledge would be present.

demonstrating an intelligent system? And perhaps just as important how can those policy-makers be said to direct or manage technology? On what do they base their decisions about technology? This was not only an odd demonstration but it was amongst the most annoying for Howard Jacobs who would turn round to see a director nodding-off in his chair. Later he remarked to me 'They asked nothing! Not even the kind of questions you ask us about what we are doing. What do they think they are doing? Do they know anything? What have they come for and what are they going to say they have seen?' Certainly a scene such as this made it hard to accept, without a touch of irony, the comment from the one 'ordinary' viewer of the Cally demonstration: 'We'll expect Peter to change if we find him going in a different direction from the rest of the world.'

According to Mark Robbins constructing the demonstrations was simultaneously constructing 'intelligence'. This is interesting in an area that is about building intelligent systems. It was Mark Robbins' view that intelligence did not simply emanate from the programs. Rather the ascription of 'intelligence' depended on an unequal distribution of knowledge surrounding the designer system - knowledge that was relative to the time spent on programming. Mark Robbins said he knew what went into the system: he was closely involved in the programming and hours spent debugging gave him familiarity with the system. Once you knew what went into it, suggested Mark Robbins, it was not intelligent[5]. But it was not a familiarity shared by the the other collaborators 'Intelligence' was a social relation[6]. In a light-hearted vein Craig Ward suggested that they select a version of the demonstrations (the 'internal' version of a module class as opposed to the 'external' version) that would show lots of 'flashy equations to blind them with science so they think it is really clever.'

The designer system, however, was to be used eventually by designers and not just demonstrated to collaborators. Craig Ward saw what he did - encoding knowledge into the taxonomy - as attempting to get the designer system to the point it could be, as he put it, *trusted* by a designer. This trust meant for Craig Ward

[5]The term 'intelligence' did not figure prominently in the department of Artificial Intelligence. For example, Jim Watson was informed by Professor Smith that he had made history by putting 'intelligent' in the title of a departmental talk: 'What makes a robot intelligent?'. Jim Watson noted, in turn, that no-one at the talk asked him to attempt a definition of intelligence.

[6]See (Woolgar, 1985) on how the boundary betwen humans and machines is socially mediated.

that a designer would not keep turning to pencil and paper to check the output from the designer system but would accredit the output of the designer system itself as knowledge or information about design. This is, however, an interesting notion of what it means to have successfully built an intelligent system in a subject like AI that has warned against what one practitioner discusses as success based upon what might appear to be 'intuitively sound' (Doyle, 1984, p4).[7]

But for Jim Watson how Cally would evaluate the success of the designer system sometimes provoked the anxious thought: 'Suppose there is only one designer system in the world, how and when will we know we have the right one?' There was, he said 'no

[7]Doyle, 1984 writes about expert systems in particular: "But if we place trust in an expert system because its information appears sound and reasonable, and because it has succeeded on a few dozen test cases, we are derelict in responsiblity and prudence, for the uncommon sense of current systems offers small warrant for success in many other cases." (1984: pp4-5) What is trust? What is the basis of believing a machine's output or accrediting it with knowlege? The reliability of a technology's output is an area to be explored: what makes a technology reliable? For example, imagine a supermarket situation where a shopper who has used a pocket calculator to tote up the cost of the shopping is faced by a different total at the bar-coded check-out till. Which technology is believed, which is the more reliable and why? What factors influence which output is believed? Is the brain brought in to arbitrate? Or is the brain redundant? In the case of a 'dispute' between the output from the designer system and the pencil and paper, which result is relied on? Does it depend on the user? How does a user accredit the output of a technology like the designer system with the status of knowledge?

benchmark' by which to evaluate the designer system[8].

A concern for collaborators Reams and BEB was that the project must be made to appear viable to the Steering Committee and to the Alvey directorate in order to secure funding for the demonstrator phase[9]. That involved making the collaborations look like a project and the technical contributions part of a system that would demonstrate factory automation to Alvey.

Constructing Feasibility

How were they to construct their work in order to continue to get the funding? How were they to present their work to Alvey and the Steering Committee? There was much mundane work to be done. How were they to make it appear as though they had a

[8]Did users provide an independent judgement? Designers, said Mark Robbins, would have to be told in advance what to expect so that they would not judge the system according to the assessment criteria of CAD; that is a system that will do a lot of drawing with some reasoning tagged on. The designer system did not do lots of sophisticated drawings and so according to this reseacher designers had to be prepared for a tool that did constraint satisfaction. Interestingly, according to this researcher, HATI, who had conducted 'usability' studies on the designer system, did not explain the system 'properly' to the designers with the result that designers expecting a CAD system criticised its 'usability': they were he said looking for a CAD system and did not get it. The complaints came back to Cally. It was this researcher's view that HATI had chosen not to 'explain' the systems' capabilities to the designers in order to boost their own views of the system: this is not what designers want in other words.

[9]During the first two and a half years of the project it was described as a 'pilot' project, in the following two and a half years the project would enter the 'demonstrator phase'.

plan and a way of going forward. They had only paper at their disposal. They must show the contributions 'going from divergence to convergence': 'We must not look fragmented, that is like nine separate contributions.' They considered how to best to draw diagrams to give an impression of a plan and of a direction; one suggestion was that convergence might be shown by diagrams which showed a continuous reduction in the number of contributions from nine to six and then to four. It would hopefully show that individual contributions gradually converged as individual sites came together to solve mutual problems. Will the demonstrator look 'noddy', Eric Cater asked the other collaborators? Should they concentrate on feedback asked Joe Blair, since they said they would do it and because it might 'zap' Alvey. But on the other hand said one of the BEB project managers they did not want to 'zap too much' or else the funding could stop, 'they might say "that's it you've done it".' So preparing the demonstrations was to be a delicate act in making several impressions upon the viewing audience: to convince them that they were on course to demonstrate a valid/commercial system *and* they still had work to do.[10]

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[10]It was also at this time that the Enabling Technology/Large Scale Demonstrator distinction resurfaced (see chapter 4). It was announced to the collaborators at a project workshop that there were enabling technologies that would appreciate a 'real-life' application like the demonstrator project. The Large Scale Demonstrators

The project, however had eventually to put on a 'realistic' show for the Alvey directorate at the final demonstration. It was also intended that work within the project was in keeping with world developments in factory automation. This was especially important for the Demonstrator Definition Co-ordinator, Phil Mann (a physicist from BEB Assemblers). It is interesting in itself that such a managerial position exists. As the title suggests, his job on the project was to define the direction the project should take for the second part of the project, the demonstrator phase and then to co-ordinate the activities of the nine collaborators in line with that direction. It was during the pilot project phase that Reams were to raise concern over what they saw as the incongruity of individual site work. How could they convince Alvey of having come up with a system that would

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were intended to act as drag on Enabling Technologies, said Deen's project manager, Joe Blair. It was therefore unfair, he objected, that they might now have to take enabling technologies on board just because those projects had gone ahead without the 'pull' of Manufacture from Design. What faced the project now, said Demonstrator Definition Coordinator Phil Mann, was how to minimize the effect on their work of having to fulfill their contractual obligation to take on board the enabling technologies; in other words, it looked as if possibly more heterogeneous engineering might be required in the future regarding this relationship. No necessary or hierarchical relationship existed between these areas of technology said to be on different ends of the research/application continuum. This is interesting in the light of the Alvey Evaluation interim report which states that passing enabling technology results onto the Large Scale Demonstrator projects had been unsuccessful because no clear framework existed for this purpose (Georghiou, 1987).

meet the stated goals as they appeared in the Study Report when some of the collaborators were focussing on problems that excluded others from making their contributions to meet their individual goals/requirements and prevented the project as a whole from meeting its stated aims. With Cally working on gearbox design, HATI claimed they had only limited material to interface to. That, in HATI's view, would not be enough to adequately demonstrate the usefulness of MMI. It was not just Cally however. According to Reams, Deen university's concentration on modelling milled parts only would mean that BEB machines were not going to be able to demonstrate anything but the most elementary of machining operations. Another Reams concern was over BEB machines who were to provide a control system able to schedule and marshal materials, tools and data to both the manufacturing cell and the assembly cell. But how was the control system to obtain information regarding materials, jigs, fixtures, given that the process planner would not be considering assembly, or jigs and fixtures?

A vital issue for Reams was the scope of the project. If the demonstrator was only able to put together simple, meccano-type parts, its wider implications for industry were close to nil: 'if it can only deal with a very restricted set of different parts of particular configurations and manufacturing methods then again its relevance will not be seen to be great (particularly if those parts are not fuel pump parts.) It is important that at the end of the project the Demonstrator must work with parts of a known product and, it must be such that it could fit into a real factory - i.e. capable of ongoing operation. The whole demonstrator must be such that manufacturers will quickly recognise its validity. If all that is provided is the ability to design one or two simple parts with IKBS help, restricted only to parts that can be milled, with considerable human assistance between design and manufacture, then the watching world is unlikely to be impressed' (project document).

Perhaps they should have a system design team, one participant suggested. That was all right, said another, if you knew what system you wanted to design. One other issue that was raised that would have to be dealt with in the course of the project was how the designer system was going to be 'differentiated' from CAD/CAM systems that had huge design teams: they should be looking for a way to distinguish the system from CAD/CAM systems that would appear more viable: they did not to have their success measured this way.

A Large Scale Demonstrator: collaboration and precursors to market products?

Cally, said Jim Watson were concerned with a general methodology of design not just a system specific to the fuel pump: in particular, they were not building an expert system[11]. They were concerned with a methodology for encoding design knowledge: not just fuel pumps (It was Craig Ward's view that Reams saw the fuel pump being neglected)[12]. Management claimed they had an obligation to the Alvey directorate and to the BEB company to 'get products out' within the lifetime of the project The concern with getting products out was, said Jim Watson, misplaced and came from management holding a mistaken view of the system: 'I don't know why Alan Rogers keeps going on

[11]The name 'designer system' had been chosen by Peter. It was, said Jim, the 'official' name of the system, not IKBS. One industrial participant assumed it was because Cally wished to avoid another 'Lighthill' and resist being accused of failure. However, although *not* referring to the Manufacture from Design project Jim Watson told me that something which 'does go on' is universities making their work attractive to industry by calling it expert systems.

[12]According to Craig, Reams' site manager was concerned about the team's apparent neglect of the fuel injection pump. To satisfy the Reams site manager, said Craig Ward, the Cally team took the drawings of the fuel pump down to Reams and referred to it to ease their mind about working on it.

about getting products out. It's too soon.'

BEB were reifying the block diagram of the designer system in seeing products, said Jim Watson. A particular problem was the 'specialists' programs which were designed to aid a designer in making design decisions for cost considerations, reliability and maintenance. It was Jim's view that BEB's concern with getting products out of the project came from seeing these as expert systems. BEB in turn wanted to know why they could not be called expert systems.[13]

[13]Neither was Cally researcher Tony Innes convinced that the 'specialists' should not be called 'expert systems'. Jim Watson's definition of specialists as systems which would give advice but not take decisions for the designer was what distinguished the specialists from expert systems. Tony Innes did not agree - 'what are they then?' he commented. Expert systems, he claimed, *were* used in an advisory role. But it was the future expectations of expert systems with powers of judgement that Jim was protecting the system against.

It is worth noting that many comments like these passed between members in the form of team - or what were called 'internal' - papers rather than conversationally. Attached to a paper would be a list of those in the group who should read it. Comments were then written down and given to Jim, often with no discussion between team members. But the comments themselves were sometimes 'conversational' in style. Tony Innes' remarks in particular,'Ugh .... what does this mean?!! This is horrible!!' Before you passed it on, you ticked off your name from the list. 'Observation', or just knowing what was going on, therefore depended on my name being on the list and making sure I got hold of any papers that were returned to Jim. Indeed much of the work in the AI lab was not 'observable' to me in the way that is most commonly represented in the science studies literature as participant observation. And the idea of objects being constituted through 'talk' (Knorr-Cetina, 1981; Lynch, 1984) also seemed a million miles away from my experience. Work is often silent; the researcher at his machine is often not aware who else is in his room with him.

Controlling the criteria of success

The specialists, said Jim, were being seen as expert systems that could be developed as products: cost, maintenance and reliability expert systems. How could expectations of such a system be controlled? Cally called their advisory programs specialists so as not to 'confuse' them with expert systems. Why were they not expert systems, said the BEB managers? As specialists it was intended that they have specialized knowledge about costing, etc., but that the control of these programs would be in the hands of the user, the user would have to invoke and could always overrule. Their name was eventually changed again from 'specialist' to 'toolbox'. A toolbox is something a user has control over, it indicates an aid to design. Said one new Cally researcher about the change: 'It's political more than anything'. 'Specialists' had connotations of inferencing and expert systems. 'Toolboxes' is to move management's expectations further away.' It was the future expectations (i.e. rising expectations) of expert systems which Jim Watson said he was up against. That was why Cally had always made it clear that the system was not intended to be used by a novice: hence the bicycle analogy. Restricting or what one worker called 'managing' expectations also involved, he said, adopting an air of 'we know, you don't'. 'Jim likes to present a sort of 'we are the university, we know''. In other words it was a case of who was entitled to confer success on the work: by *whose* criteria.[14]

It was indeed often Jim Watson's view that, 'it's up to us to say what can be done, what is possible.' And as the newly-appointed intelligent robotics lecturer one thing that bothered Jim was, ironically, recent interest in robotics. This interest was not entirely comforting for him; it did not signal robotics arrival to a position of credibility. Robotics had entered into the public imagination in a way that might not reflect what went on inside AI laboratories. What were these interested parties expecting? And what would happen to their work if they did not meet these expectations? What Jim spoke of needing was to avoid was another Lighthill-type criticism.[15]

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[14]However, one researcher told me that expectations had to be managed carefully. You could not give the impression that your collaborators were getting nothing.

[15] Why do they need to control expectations? I am not satisified that this is a sufficient explanation. Does controlling expectations suggest some awareness of what is involved in making a system 'work'? Harry Collins enculturational model (Collins, 1985) of knowledge suggests that AI systems work because the user fills in the gaps: i.e compensates for the knowledge (everyday understandings which we have as a result of belonging to a culture, to participating in a form of life) which cannot be encoded in a machine in an algorithmic form. But just how much is a user being expected to fill in when it is an expert system and what kind of user is expected to use it? Expectations of expert systems were rising all the time said Jim Watson.

The 'simple and well-contained' problem of encoding the design knowledge for simple gear parts that appeared 'unrealistic' to Reams was, said Jim Watson, suitable for Cally's software. Fewer collaborators; that after all was what DAM, the original project was all about. There was even one suggestion to minimise collaboration within the project to just a few collaborators: to those who supported Cally's technical project. Demonstrating the principles that would design and use that knowledge to assemble a part. One Cally researcher saw Manufacture from Design 'as one big detour to get back to the original project, design and make.' One researcher from Talcot suggested, 'we can allay their fears, tell them we're doing this modular stuff and get on with doing integrated work.' Another site manager, Nancy Thomas of BEB Assemblers, described herself as half-researcher and half-industrial worker because of her role as a researcher in an industrial research centre. She could see both approaches, she claimed. It was as though she embodied both approaches to the design of the system. (Barnes, 1971).

Although this minimal version of the project was not

Was this equivalent to saying that users are expecting to use less skill and companies like Reams were hoping to use multi-skilled workers, that is less specialized workers?

adopted, it was 'too soon for products' claimed Jim and in his defence he was going to show BEB a New Scientist article claiming that it was 'Too Early for the Factory of the Future'. This was *research*, Jim pointed out to some visitors to Cally. One visitor from Cally university's mechanical engineering department who saw the demonstration doubted the economic viability of the method for encoding knowledge into the taxonomy. That, he said, would be a major obstacle to its commercial success. A company, he claimed, would have to put their best designers onto the job of loading up the taxonomy. And that, he said, would take many man-months. That amount of time was too costly for a company. It was doubtful that companies would want to do this. Craig Ward having worked in industry agreed with this. But Jim Watson responded, 'We're not concerned with that, this is research.' So how was Jim Watson going to define this work as research and to keep control over (and define?) the criteria of success?[16]

The 'nature of the problem', for Jim, involved exploring the technology for what he called a 'truly' flexible manufacturing

[16] I have no evidence, however, that the industrial collaborators on the project saw this as a 'problem'.

system. This was, according to Jim, a vital stage that BEB and Reams were leaving out. According to Jim they considered the work as moving from research to development. The industrial collaborators, claimed Jim, ignored the 'nature' of the problem: but that in Jim's view was to miss out a vital stage.[17] After a session of Masterclasses intended to bring the other collaborators up to date with Cally work, the team went to the pub afterwards to discuss the session. In particular we discussed why the collaborators seemed pleased with the Masterclasses at the end of the day. This concerned the team: why were they pleased, what did they expect? One researcher who had worked in industry suggested that they might be pleased because Cally had represented their work as sets of tasks progressing serially and numbered 1.1., 1.2 etc. This he said probably gave the industrial collaborators in particular the impression of stages completed that could go onto be developed. And so fuzzying the boundaries between versions was one suggestion.

Jim's future position within the Cally AI department was

[17]But was it not a demonstrator project; the idea being that it was to get out products driven by industry.

not just as manager of an Alvey large scale demonstrator project but as lecturer in intelligent robotics. He wanted to stay in Cally and in academia; he had no intention, he said, of going back into industry. There were noticeable changes in his personal style as time went by: the smart shirt and tie, jacket and attaché case were replaced by leather jacket and backpack. The former 'props' were now reserved for technical committee meetings.

The lecturership was a post in which Jim Watson needed to publish papers to establish his academic career. With Peter's eventual departure to the United States, Jim was keen that there should be continuing research in robotics using the designer system work. Robotics at Cally should not be thought of as going with Peter[18]. Not everyone on the project was convinced that the designer system had a future without Peter. His departure was a source of some concern: one programmer explained how Peter had been responsible for all the implementation and that without him, he was not convinced that there was enough 'momentum to keep going'.[19] Many on the Cally team wished to

[18]When Peter left he gave a lecture in the department about his last twenty years working there. After the talk Jim told me that retrospectives were all very well but that he was looking to the future: and that robotics work at Cally couldnot be seen to have gone just because Peter and another colleague had left the department.

[19]It was Peter who was responsible for such fine-tuning as simplifying the

publish.

Professor Smith of the AI department said they were now in the 'real' world. They had to make some compromises. That was absurd, according to Howard Jacobs. He had come to a university to be able to publish - his career, he claimed, depended on it. If he had wanted to work in industry he would have gone there. He wrote down these comments which he called his 'flame' but in the end he did not show to Professor Smith.

The Politics of Publication

Cally's work appeared as papers not just demos. For Cally

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algebraic manipulation engine Press , to suit the designer system. The designer system did not need all the capability of Press, so Peter came up with the idea of simplifying it into what he called mini-Press. It was hoped that mini-Press would speed up algebraic manipulation for the needs of the designer system. The method of testing the capacity of Press against mini-Press was also typical of Peter's style. The test was actually a race to see which program was quicker. And so with the screen divided down the middle, Press and mini-Press were put in the starting blocks. They were each set an equation and then to the sound of Peter and me shouting 'Ready, Steady, Go' they were off. It was then like watching rain drops racing down a window, but we were egging-on the same competitor. When mini-Press won, Peter cheered with delight. He then asked me to choose an equation in the way an entertainer might ask an audience to think of a number. I chose tan x =y+1, but this time mini-Press stumbled at the first hurdle. 'It's crashed', said Peter and turning to me said, 'I thought you didn't know any maths'. It seemed that choosing the equation had given me some credibility and I was very proud to have tan x=y+1 called after me. At talks, 'Anne's equation' was referred to as the sticking point for mini-Press.

presenting the work as papers was important - especially for Jim Watson - to get to academic peers. For the industrial groups and for the Demonstrator Definition Coordinator papers needed to be protected from the potential scrutiny of competitors; in economic terms that meant knowledge which represented a possible return on investment.

But how might papers be used, who would they help? The industrial teams depended on the Cally team to answer these questions. How were they enlightening competitors who would read Cally's papers? What clues were they giving away? If Cally were to 'gaze into their crystal ball', Eric Cater of Reams asked, 'what could they see in the future?' There was nothing you could actually 'kick or see or feel' as yet said Cater, but were their ideas in this area going to help someone working on similar problems to get a marketable solution first. What could be done to stop them? Could they see others picking up on their work? It was generally agreed that flow diagrams and algorithms would make technology available to others but in the papers what else could be revealing the designer system to potential competitors? An increase in length of time that BEB wished to take to assess the papers and take precautions to protect from competitor scrutiny was in Cally's view too long for Cally to be able to present papers at conferences or to submit to journals.

Indeed, Cally's desire to publish affected the definition they gave to the designer system. The Functional Unit Module Taxonomy was changed to 'Encyclopedia' and the designer system, was renamed 'Cally designer system'. The idea was, said Peter, to turn Cally's work into 'a hypothetical system', independent from the Alvey funded project: one which they could talk about in principle. In other words, Cally's designer system as opposed to Manufacture from Design's designer system. Cally, Jim Watson claimed, needed a way to talk about the designer system. They needed, said Peter, to *'decouple'* the designer system from the project as a whole. As part of a demonstrator project they did not have access to the IKBS 'club' where they could discuss their work with other researchers in the IKBS field. And Jim needed a way of getting known in academic circles (in hindsight he told me that he regretted going along with the negotiations that had led to the project being classified as a demonstrator project and not as enabling technology). They were, said Jim, shut off from a forum in which they could talk to other academics. But instead of, as Jim Watson put it, 'setting a precedent' for the publication of papers, which was Cally's intention behind changing the names, the terminology had the unintended consequence of making the concept of the 'taxonomy' clearer to the industrialists. According to the project managers from the industrial teams, 'Encyclopedia' had an everyday usage. If, by analogy, it made things clearer to them it was likely, they suggested, to make it clearer to those who might wish to do something with it.

One suggestion from Jim Watson was for BEB to make applications for patents. That way, Cally suggested, they could write papers and BEB could protect 'results'. But what was it, asked BEB, that was patentable? What was it, in other words, that was to constitute 'new' knowledge? And how were they to accord something the status of new knowledge?[20] In BEB's view since Cally was amongst the world's leading AI universities the rest of the world would probably be looking to them. It was, said BEB and Reams, a pecking order that included the collaboration of universities with industry. It was BEB's view that the universities constituted a league table: 'where do you put yourself

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[20]An interesting analysis would be a study of the social processes which lead to the acceptance or rejection of a patent application thereby assigning it the status of 'new' or not 'new' knowledge.

on that pecking order and where do others see you?'. (Indeed according to the demonstrator definition coordinator part of BEB's reason for being on the project was the reputation of Cally university.) For the industrialists then 'knowledge' was not independent from a network of AI researchers collaborating with industry. A network with which they were not familiar, but which they suspected existed. The academic groups which Cally wished to address were, said Eric Cater, most likely to be working with the industrial groups: 'The Hewlett-Packard and IBM's must be looking to see what comes out of here.' What were they giving away? Where would Cally place itself on that league table? Who was going to be taking notice of the references Cally cited? What about the interpolation of tables? Cally tried to persuade BEB and Ream's that anybody working in field of AI design systems would be addressing similar problems. But, asked BEB, were they using the work that Cally was citing in the same way? Were Cally giving them the vital piece of information they needed? Were Cally doing themselves a disservice, BEB asked, by assuming that others working in this area would not necessarily be looking to Cally?[21] It was the removal of

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[21] It was a tricky situation for BEB and Reams. As BEB's project manager explained, they also needed Cally to publish in order that they be seen to be associated

references to bodies of work which the industrial collaborators wanted: references which in the industrialists view could direct competitors to a body of knowledge that might lead them to solve an existing problem. Removing those references, said Cally, would knock them off any top position they might hold in the academic league table.

References were essential to Cally. They needed them as Jim pointed out to the industrial collaborators to show 'that our work is based on good stuff' (See Latour 1987 and, Gilbert 1977). Since it seemed to Cally that only references roused BEB's concern, Cally constructed an elaborate scenario intended to provide BEB and Reams with a definition of the situation at meetings, which they hoped, would ensure important citations stayed in the text. The idea was to load future papers with two sets of references: the ones they wanted to keep in the text and 'decoys' with which they planned to catch BEB and Reams attention. It was not yet worked out how they were to appear in the text but when BEB asked for their removal they would initially put up a fight which having learnt from previous dealings

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with a reputable and highly regarded university - that is one that had papers published.

would 'alert' the industrialists to the potential 'importance' of these references. BEB would pursue the removal and Cally would gradually submit[22]. BEB, it was hoped, would feel like they had won and allow the publication to go ahead with the 'real' references Cally wished to keep in the text.[23]

Different views within the Cally team

Not all members of the Cally team gave publications as high a priority as Jim. Although the names of the other workers would sometimes appear on the papers, Mark Robbins was one who did not understand why his name should appear as a contributor or co-author. According to Mark, he could not write with any certainty what Jim had to say about the designer system. The designer system, as he worked on it, was not experienced with the same degree of certainty as it appeared in the papers that Jim

[22]This type of communicative behaviour has been studied by Goffman (1970). He writes: 'The subject appreciates that his environment will create an impression on the observer, and so attempts to set the stage beforehand. Aware that his actions, expressions, and words will provide information to the observer, the subject incorporates into the initial phases of this activity a consideration of its later phases so that the definition of the situation he eventually provides for the observer hopefully will be one he feels from the beginning would be profitable to evoke' (Goffman, 1970, p.12)

[23]If references *are* left out of papers to protect commercially-sensitive knowledge then how accurate are co-citation studies at describing an intellectual field for the purposes of making policy decisions? Similarly, strategies such as changing the nomenclature of a system might affect the accuracy of keyword analysis.

wrote 'I would always have to add some qualification; it can do that sometimes, doesn't do it quite like that. I'm never that certain. Jim would make claims for what it would do in the future.'[24] He said he would be no good at conferences where he would be expected to talk to others about the system. As a result he did not go to them. Indeed, at one meeting this worker deliberately chose to present *handwritten* slides of his talk about his work, which, he explained, was because he was not certain about what he was doing. He could not say anything with any certainty in the manner of a paper, and interpreted how he differed from Jim as the result of their different roles in the production of knowledge, 'I suppose Jim has to sell it.' When it came to selling the system Jim had the ability to take what Mark considered to be risks, claiming it could do things Mark felt it could not. And most importantly he had the knack of getting himself out of tight spots. When asked if the designer system could recognise as a contradiction a hole so big it would obliterate the side of a cube, Jim said it could. Mark, who was demonstrating, knew it could not. Luckily he did not have to demonstrate. Jim was able to use what Mark called 'human' terms[25] to get himself out of a tight spot: 'he'd say, "oh, you

[24]See Collins (1985, p145) on certainty and social distance from the site of knowledge production.

misunderstand me, I meant it could do it, *one* day"'.

Mark continued, 'It's never that certain to me. Integration dissolves when you get close up.' Along with 'modularity' he suggested integration was an abstract notion. As a result papers were not accorded a very high status by Mark Robbins; they were, as he put it 'waffle that anyone could write.'

This worker referred to Jim Watson as someone who saw himself 'as a bit of swashbuckler, a bit like Errol Flynn.' He went on, 'He thinks the designer system is revolutionary but it isn't. It won't stand up to much prodding.' However, it seemed that the ability to make jokes[26] about the system (and laugh at them!) and to criticise its shortcomings was related to the degrees of

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[25]Such terms were anathema to a mathematician like Mark Robbins. It was his view that it was a feature of AI that terminology was so indefinite. Discussions with Jim were likely trying to hit a 'moving target'. There was no commonly agreed terminology as, he claimed, there was in physics.

[26]Once over tea Craig Ward and a colleague were laughing about the inability of the designer system to design a gearbox let alone the vastly more complicated fuel pump. When I asked him if he had no confidence in the designer system, he answered me in a surprised tone; "Oh come on Anne, we don't have to bullshit *you*. *You're* one of *us*. We give others the gloss." Craig Ward's comment is also interesting in terms of what it says about the access a participant observer can have to the world of the technologist: private thoughts on the technology might be quite different to what is presented to the 'outside' world, even when the participant does not always appear to be a member of her group!

closeness to the designer system; those closest to it would joke about it. However, 'Jim gets very defensive about the designer system', said Mark. Even within the team itself Jim, said Mark Robbins, would not take a light-hearted joke against it. Mark felt this defensiveness was not justified, especially since Jim, as manager, was not as close to the technical development of the system.

Indeed not everyone was that bothered about publishing either. 'I can see BEB's point' Craig Ward told me, 'but if the whole team left over publications I could hardly work all these workstations on my own.' And so he went along with the rest of the team. Craig wanted to see something get out that he could say he had been apart of. Craig liked achievements. His successful weekend mountaineering trips were marked on a wall-chart he had on our office wall. Each triangle filled-in with red crayon marked another munroe conquered. He was proud of the large number he had climbed.[27] Craig looked on Peter's eventual departure to the States[28] as possibly a way of speeding

[27]He was also very proud of his British Telecom shares. Each morning Craig scoured the paper to see how they were doing. None of us were able to advise him, however, on when he should sell to make the quick return he dreamed of!

[28]After Peter left the project for work in the States one researcher feard that without him there would be insufficient momentum to keep the thing going. It was all

BEB up to get something out. As he argued: 'They'll be afraid he speaks to others.' BEB, according to Craig, had paid Peter vast amounts of money not to talk about his work. But, Craig added, 'that would be like rape.'[29] He looked forward to what he called the 'End of the Revolution.' Instead of the flying-sheep he said they should have a project T-Shirt which would contrast the designer system to the dark satanic mills of the first industrial revolution: 'The designer system will show happy people picnicing on green grass.' 'But software is like a soap-bubble' said Craig 'unless you do something with it bursts.' He left the project, he said, with the belief that 'the designer system has kind of gone as far as it can. It sort of went when Howard and Peter left.'

Peter's ideas said another. 'When we get stuck we'd just ask Peter'. After each stage of demonstration of their software Craig said there was a sense of 'Now what do we do?' 'We didn't know where we were going. Peter did everything. And Jim hadn't really been involved in the programming.' The work itself was distributed at Cally team meetings by Peter and Jim to the other team members. For most of the time I was on the project it was really just Craig and Howard were given work to do: putting modules into the taxonomy. It was called 'homework' which was indicative of its status as something to be completed before the next meeting and the next assignment.

[29]I squirmed visibly at the use of rape in this context. Craig then commented, 'well you know what I mean.' I didn't. It seems that quite a bit of sexual/power language surrounds men and their contact with science and technology. The Noble prize-winning physicist Richard Feynman described science when first encountered, as being like an exciting lover. Over time science was like a wife. Nature here is portrayed as the feminine over which men exert control. It seems that for Craig Ward the technologist who is held back from talking about or publishing the results of his encounter with technology experiences the violation of his rights and his freedom: an experience akin to rape. In other words, when the technologist cannot control the genders are reversed: it is like being a woman.

Chapter Ten

Conclusions

Theory revisted

This thesis began by reviewing some important theoretical approaches which have attempted to explain technological change. It is now time to draw together the empirical material of my case-study in order to see how these approaches bear up in the light of such a study.

The Marxist approaches

Hirsch's state theory sees state funding of technology as part of restructuring of capital in periods of crisis (Hirsch, 1978). There is however in this approach an implicit acceptance of the capitalist nature of the technology which leaves the creative process unexplored. Just how the nature of that society impinges on or shapes technology is neglected. The result is that technology remains firmly within the black box.

Noble (1986) on the other hand is a Marxist who *has* looked at the process of technical change. He has explored social choice in the design of machine tools and has argued that neither 'technical' or 'economic' factors are the decisive factors in technical design. They are mere rhetoric, justifications behind which the real impulse is to control labour. The goals of technologists (engineers) and management are inextricably linked; the ideology of capitalist domination, the 'queer quest for power and omnipotence' all lead to the choice of technologies which deskill and control labour.[1]

Noble suggests that this quest for power and control over labour continues with the factory of the future and the use of Artificial Intelligence in manufacturing. Cooley (1981), in a similar vein 'predicts' the continuing trend to deskill mental labour - specifically, design work - that began with CAD systems. He has argued that expert systems will continue this process.

In this thesis I have shown that for the Cally technologists there were indeed different views on how to design the designer system; this focussed on how much the system should do and how

[1]There is however a contradiction in Noble's argument. If the engineers design what they know will find favour with the managers and the capitalist ideology dominates then how can there also be social choice in technical design? The *existence* of choice does not appear to be consistent with his approach.

much the designer. The more 'conservative' appoach in this regard was chosen over the more 'radical'. The criteria which influenced Cally's choice was existing work which was familiar to Peter and which in the area of VLSI design had been successful. In part the particular historical circumstances of the AI community also seem to have been influential in that choice. Accusations of failure as damaging as the Lighthill report for example was not an experience to be repeated. In other words, these factors seemed more crucial to the choice than an 'impulse' to attempt to encode within the machine powers of judgement that would allow the system to use as Innes put it 'average' as opposed to 'good' designers.

But what about the industrial collaborators and the shaping of the designer system and the manufacture from design project? The Marxist literature sees the process of technological change as informed by clear goals - capitalist goals. But this is not what I found. They are not a homogeneous group. BEB were interested in getting out products. But what were products? The industrial collaborators experienced much chaos in how to organize the various collaborators and the language of AI was unfamiliar. What work going on at Cally could be identified as 'new' IKBS knowledge was not self-evident to the industrial collaborators. They had to rely on the academics to show them. Reams' Eric Cater does appear to have expressed a concern that the designer system 'put brains inside the designer system' and use less highly trained designers; he suggested that perhaps Cally's taxonomy was not the way to represent how designers think. He enrolled the help of the MMI team but as we saw their place in the project was to be negotiated with Cally.

This study, however, cannot offer a knock-down to a possible riposte from a Marxist approach. The Marxist critique is levelled at the inappropriateness of participant observation to an understanding of the shaping of technology. It argues that 'technology' happens elsewhere; 'behind the backs' of the researchers in any one laboratory and that technology is not shaped by the activities of individual capital.[2] Rather, capital is conducting a series of experiments in technological and managerial innovations in order to overcome the current crisis in

[2]From the sociology of knowledge approach Trevor Pinch (, 1986) criticises laboratory studies in technology where the key actors (the core group) are spread over several sites. This means that a partial picture emerges since activities pertinent to the site being studied may be taking place elsewhere.

the established pattern of relations between capital and labour and create a new basis on which to accumulate capital (Aglietta, 1979). Social shaping in this context means that new technology is shaped by the struggle to establish a new pattern of capitalist exploitation which does not mean that control over the labour process is an overriding imperative for capital in this restructuring.[3] It is also claimed that there is no logic determining which experiment is going to be successful in terms of its relation to the profitability of the innovating company or its compatibility with emergent patterns of exploitation. Perhaps, then, the Alvey programme as a whole or some of its projects will turn out be unsuccessful experiments in the attempt to establish a new basis for exploitation. However, questions remain: how does that notion of success enter into the everyday practice of technology? Do technologists work towards conformity, making explicit choices and selecting what they work on or are they working in the dark on pot-luck projects which at some level are deemed successful? We are still left with the problem of how to study technical change.

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[3]Control as the principle reason for has been criticised by Wajcman (, 1986). Capitalism is based on the need to accumulate capital. It is based on valorization (increasing surplus value). So the question that comes to mind when Noble posits the drive to control labour as the reason for choosing one technology over another is why control; how can it be control for control's sake in a society that is driven by the need to make profit?

But perhaps any reference to capitalism or to a pre-existing society which shapes the technology is misplaced. Perhaps Latour, Callon and Law are right and the technologists were shaping both technology and the social world according to their own goals and interests. Certainly we have seen them interweaving the 'technical' and the 'social'; with the modeller[4]. Even the rhetoric of Alvey's MMI policy was negotiated at the level of the project as Cally sought to protect the 'cognitive capabilities' of the system (the representation of knowledge) as *their* area of work. Jim Watson also held strong views about the changes that were required in the social world in order to take on the designer system. But he did not seek to engineer those changes. He did not go out into industry to upset the status of designers and accountants within companies in order to take on board the designer system. Nor did he persuade companies to get ready to take on board an integrated system. Perhaps, thought this does not mean that Latour and his colleagues are wrong. Perhaps my participants are just poor heterogeneous engineers. But what and whose 'reality' are we

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[4]Here however we saw that heterogeneous engineering had its limits as far as Jim Watson was concerned: a modeller from another supplier depended on getting the go-ahead from the head of the department Professor Smith.

talking about? 'Realistic' *research* as opposed to products required the publication of papers. We saw how they wrote papers - employing 'textual' strategies in an attempt to get them published while at the same time trying to establish the independence of the designer system from the rest of the project. Jim Watson's career at Cally, where he planned a future around his post as lecturer in intelligent robotics, depended on being able to publish and extend the work of the designer system. Activities then might be said to be geared towards *future* investments. In the meantime they sought to control the criteria of success of their work and simultaneously *who* was entitled to confer success upon the designer system. It was too soon for products in other words.

So before dismissing the Latourian perspective (at least as inapplicable to this case), it is important to take into account the possibility that the goals of the heterogeneous engineering of the academic participants were actually modest: they wanted to be successful academics, rather than to produce a product, much less to revolutionize British industry. That may be so; although it also seems the case that the more modest goal grew in salience as the grander ones seemed less feasible, and perhaps *because* they seemed less feasible. More generally however, any Latourian perspective needs to take account, it seems to me, actors propensity to take large chunks of their technical and social world as 'given'. Most of us, most of the time are heterogeneous engineers in only a very limited sense. To put it another way, while the Marxist approach has a tendency to reify the social, the Latourian approach underestimates the thing-like character of the social world as it is perceived and acted within by participants.

Participant Observation: A Technique of Control?

What happens to ethnographic work and who sees a use for it? Who might you be bringing your knowledge back to and what for? The classical sociological answer has of course been that ethnographies are produced to help understanding of the social world. But a response to my work suggested that there might be circumstances where 'understanding' could shade into 'control'.

I was approached by one evaluator who was interested in how my knowledge might help them to understand how academics and industrial partners can be made to collaborate in technological development.[5] He felt that my amount of contact with this particular group of technologists and industrial collaborators could help evaluators make recommendations for how to improve participation. He referred to what he claimed were Jim's inconsistent account of expert systems which this evaluator said presented conflicting views about how he saw these systems. I, however, was assumed to have got *closer* to these technologists than the evaluators, and as a result was assumed to be privy to a more consistent view: what did they really think about things? What was it that might inhibit collaboration and what could I suggest as a way of resolving it? How could this schism be resolved between industry and academia? The evaluators were not the only ones. Manufacture from Design's monitor, responsible for monitoring progress also took an interest in my presence on the project. The Alvey Directorate, he said, wanted as much information about what was going on; it was possible, he suggested, that I could supplement the work of the evaluators. We cannot, therefore, neglect the

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[5]The evaluators in turn have been criticised by the Cabinet Office's chief scientific officer, John Fairclough, for not being able to recommend the path that technological developments should take in the future to enhance Britain's technological capability. The evaluators have explained that was not their task. This seems to suggest that the evaluators were expected to identify technological trajectories which the managers of technical change could then use to direct funds. However, see MacKenzie (1987) for a critique of the notion of technological trajectories.

possibility that under some circumstances the ethnographer of science and technology might be engaged in similar work to the scientist of technologist. Latour has described the work that scientists do as a process of turning messy reality into traces, inscriptions on paper, making implicit knowledge explicit and turning beliefs into knowledge. The acquisition of knowledge is like building a trap: it allows those in possession of such knowledge to control at a distance, to take decisions based on simplified information: production curves and equations are simplifications that enable such control: All these objects occupy the beginning and the end of a similar accumulation cycle; no matter if they are far or near, infinitely big or small...they all end up at such scale that a few men or women can dominate them by sight; at one point or another, they all take the shape of a flat surface of paper that can be archived, pinned on a wall, and combined with others; they all help to reverse the balance of forces between those who master and those who are mastered. (Latour, 1987)

Is the process Latour describes for science and for the exploitation of one country by another applicable to the microstudy of science? Perhaps ethnographers are guilty (or potentially so) of the same imperialism which Latour describes. We may be part of what Latour calls the cycle of accumulation. Is participant observation a 'neutral' methodology? Or is what Latour describes as the behaviour of his technoscientists also applicable to the social scientist doing participant observation, he will gain an edge only if the other navigators have gotten a way to bring the lands back with them in such a manner that he will see Sakhalin island, for the first time, at leisure, in his own home, or in the Admirality office, while smoking his pipe. (ibid)

Does the study of *science* and *technology,* closed worlds to most of us, vindicate the rights of the sociologist? This question stems from more than the enquiries of the evaluators and the monitors of the Alvey programme about my work. It is not just about one case-study but about the general process of accumulating knowledge. I base it on my experience of a meeting of the Science Policy Support Group in Nottingham April 1988. The point of this meeting was to present project proposals to the Economic and Science Research Council with reference to the ways in which science studies could be useful to science policy.

Ethnographic work it was suggested, could be justified to the funders if they knew that a company like Xerox Parc employed an ethnographer. Another sociologist suggested that his videos of workers were liked by the management team of the company in which he was doing his research; he did not have to justify them. And from this experience he felt that the language used by sociologists to describe their work was quite familiar to others. But no-one at this meeting asked *why* ethnographers were employed by big organizations. What use did these companies have for their work; what do they believe they are getting to make it worthwhile?

Are social scientists privileging the sociologist when they do not ask how it is that sociology can make itself accountable to funders? Or why it is that managers are quite familiar with the language of the sociologist; why it makes sense? Where does reflexivity stop and why? What are the politics surrounding reflexivity? Pursuing a strategy of special relativism (Collins, 1983) - denying that reflexivity poses a problem - is too glib an answer to these questions.

Methodology: Gender Issues

So far this thesis has seen me described as a spy, a psychologist and an ally of the human factors approach. Up until this point there has been nothing to distinguish this thesis from any other participant observation theses in the sociology of technology that might potentially be written. But there is in fact one vitally important feature; this thesis has been written by a woman. Why is that important? Woman are notable by their absence in the microsociology of science and technology. The glittering work that lights up the journals has been done by men; Collins, Latour, Woolgar and Law are practically household names in the discipline. These analysts emphasise the importance of acquiring native competence to a sociological study of science and technology. What they do not describe, however, is what it is like to be an observer in a lab.[6] As a reader of their work I was left with the feeling that native competence was acquired by dint of being clever or the result of some mystical process. I wish to be more concrete and describe what it was like being a woman doing participant observation and how gender bears on native

[6]Throughout this thesis I have tried to include details of how the collaborators saw me. It seems odd (and incongruous with their approach) that those theorists concerned with the way scientists and technologists see and manipulate the 'social' and 'natural' worlds should exclude from their studies the way technologists or scientists view (or don't view) the 'observer'.

competence.

One of my earliest introductions to the world of Alvey and new technology was at a conference designed to bring together academics and business - big and small - to discuss the programme and its importance in rescuing the poor position of the UK in the international technology stakes. Since it was one of my first encounters to the world of business and technology I expected it to be incomprehensible. But it was very familiar. The first speech explained that with the Alvey programme the UK would no longer be the 'proud' owner of the 'booby' prize for technology anymore at which point the speaker took from a carrier bag an 'outsize' bra. This started the ball rolling. Subsequent speakers sought to wind the joke into their own talks. Each was a desperate attempt to upstage the preceding one. Having seen the booby prize, it was clear to the Alvey director, Brian Oakley, why he was dealing with The Information Technology Systems of the Alvey programme. When the proceedings stopped for lunch I found myself eating a three-course, slap-up meal with many who had been enjoying the show so far. One man apologized to me for having a 'technical' conversation with others sitting at the table. We reconvened and the banter did not relent; the last speech attempted to round off the whole day with a request to meet the owner of the bra, I don't care who she is as long as she's blonde, got good legs and is under 30. Needless to say he brought the house down. Staying around for tea to discuss the conference was not something I felt inclined to do in order to do my 'sociological bit'. I wanted out of that conference room as quickly as possible. I knew very well what counted for a joke in this culture (Collins, 1983; Gilbert, & Mulkay, 1984) but at such a big impersonal venue I could choose not to participate - it was not vital that I spoke to anyone there. That was not going to be the case with my research on the Manufacture from Design project.

<u>At the Cally site</u>

The Cally team seemed to be like me. Most of us were around the same age. We spoke about films and t.v. But there were major difference too. When I attempted to hang a picturesque calendar on our office wall, Craig asked me, where are the pictures of the girls in swimsuits. And don't you like my new folder with the girls in swimsuits, where he kept his notes for the Expert Systems class. The job advert for a research post on the team should show, he suggested, a buxom blonde in a bikini wearing a sash with Manufacture from Design across it. Come to think of it, he added, that's who we want on the project. I was also told by Craig that I would have to sit in the corridor when the project got *their* '24 year old French girl researcher'. There would not be enough space for all of us in the one room. I was told that I my clothes were too dark; I was too 'school marmish': Why don't you dress like the girls outside, in nice bright pinks and purples.

My notebooks seemed 'soft' compared with the notes I imagined male sociologists kept. At first I did not want to write these things down. I thought they made me look soft too. I thought if I was a good sociologist this would not be said to me.

With the industrial collaborators I was rebuked for not accepting an open door; even though I was busy talking at the time and was not aware of this gesture. I was accused of flouting chivalry in the face so I attempted to explain how I had not noticed the door incident. The meeting was delayed a good ten minutes while I received a lecture on the 'fairer sex' and feminist women 'taking things too far.' When the meeting finally got started one participant made the point of sarcastically addressing his remarks to 'Men, Women, the whole World!' while looking at me. I also had to listen to such comments in the pub between industrial collaborators who suggested that one of the female participants in Manufacture from Design was in the project to 'find herself a man.'

In many of these circumstances I found it difficult to get into confrontational situations. I worried that it might jeopardise my acceptance and the ease with which I could be considered part of the project. On one occasion when I did speak out I experienced the 'silent treatment' from one researcher and this made me nervous of having jeopardised my work. I worried about how I should not have done this for the sake of the research! And I was very aware of the effort I was making to smooth things over so that he would talk to me and so that I could ask him questions.[7] For me the 'participation' in participant observation sometimes meant complying or being silent: I felt I was participating in my own put down and that of other women.

[7]The ethnographic worker, Knorr-Cetina (1981) advises, must not be afraid to ask questions. I agree, however one of my attempts to question an industrial participant received the reply, 'don't you worry yourself about that.'

These comments were by no means common to the team as a whole. But I think it is important to discuss. Because I was comparing myself to men who did not write about similar experiences I thought that sometimes I was failing. And I felt guilty at 'attracting' these comments. I took them to be personal faults - if I was a good sociologist, I reasoned, I would not be attracting comments like that.

Perhaps an important part of those male analysts 'ability' to acquire native competence is because they have a head - or more exactly, gender - start. They are more obviously 'one of the lads.' I do not want to put women off doing ethnographic work but neither do I wish to ignore these experiences and thereby continue to give the impression that native competence is achieved independent of gender. The ease with which a researcher acquires native competence may in part be a function of gender, and questions of gender thus enter the methodology of the sociology of science and technology at the most profound level.

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